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FRESH- AND BRACKISH-WATER VERTEBRATE-BEARING DEPOSITS OF THE PENNSYLVANIAN OF ILLINOIS

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ABSTRACT

Vertebrate remains from the Pennsylvanian of Illinois have been obtained from deposits of the following types: red beds, sandstone channel fills, gray clays, including nodule-bearing beds associated with coal, black carbonaceous shales, and coal. The types of vertebrates recovered differ widely with the conditions of deposition. This is shown in a review of well-known localities for which new faunal lists are given, based on recent revisions, and of studies of new localities. Additions to the known Pennsylvanian faunas have come from the new localities. The fish faunas are shown to be close to the descendant Permian faunas. Analysis of the tetrapods, which are principally amphibians, emphasizes the inadequacy of the knowledge of amphibians and reptiles from typical Pennsylvanian deposits. It is probable that future work in Illinois will add to the knowledge of the Pennsylvanian vertebrates of the state but the chances of discovering extensive deposits containing well-preserved vertebrates appear to be remote.

INTRODUCTION

THE SCOPE OF INVESTIGATIONS

Scattered occurrences of vertebrates in fresh- and brackish-water Pennsylvanian beds in Illinois have been reported since the middle of the nineteenth century. Two localities, one near Oakwood variously called the "Danville locality" or the "Vermilion County locality" and one at Mazon Creek and vicinity, have received the attention of a large number of paleontologists. These finds and various reports of vertebrates in other nonmarine beds prompted the writer to search for additional localities in an effort to obtain better understanding of the fresh-water and terrestrial vertebrates of the Pennsylvanian. It was hoped especially that new finds of tetrapods might be made. These efforts have met with only moderate success but the possibilities of the state are not exhausted, and it is anticipated that this work can be carried on in future field seasons.

The type of deposit in which the Oakwood locality specimens occurred seemed to offer the most promising avenue of approach, but, as discussed more fully under the section entitled "Red Beds," this study has as yet yielded no positive results. It was considered futile to attempt to search the Mazon Creek type deposit for vertebrates. The fossils, which are predominantly plants, occur in ironstone nodules. Vertebrate remains are rare, and satisfactorily preserved specimens are found only very occasionally. Almost all recorded specimens have been found by persons searching for paleobotanical materials. No effort has been made to obtain new specimens from this series of localities.

Since exposures of the Oakwood type had little to offer and a search of the Mazon Creek area was deemed futile, investigation was directed toward a study of channel deposits which occur at several places in the state. The channel deposits which have been visited suggest that exploration of these sands and conglomerates offers a fruitful field for research. One, the Falmouth Channel, described in a later section, has yielded a fairly large number of specimens. A second, the Salt Fork Channel, has yielded fragments. Other channels, one in Vermilion County and one near Mazon Creek, have proved to be barren of fossils. As additional deposits of this type are located and studied important additions to the Pennsylvanian vertebrate fauna may be expected.

TYPES OF VERTEBRATE-BEARING BEDS

RED BEDS

The red beds of Illinois are sufficiently widespread and so similar in appearance to red beds of other areas which have produced vertebrate faunas that they are worthy of special consideration. The beds which yielded the Oakwood specimens have been called red by some students. There is, however, considerable confusion concerning them. E. D. Cope[1] mentioned them as dark gray and black shale. Gurley, who collected the bulk of the material, spoke of the beds as gray. R. L. Moodie,[2] who visited the locality and carried on relatively unsuccessful excavation, described the beds as red and gray shales. Wanless, in a personal communication, states that the beds are mottled red and gray. The writer has visited the locality several times and, although the precise position of the deposits was not seen, being apparently covered by slump, the horizon is clearly one of red and gray mottled shale. It is clear that the bones and teeth were associated with red shales although they may have come from the gray or black parts of the bed. Some of the bones show brilliant red stains and others are enclosed in a gray, nodular matrix.

There are several exposures of similar deposits in the vicinity of Oakwood. The writer, accompanied and aided by Dr. Ernest P. Du Bois, then of the Illinois State Geological Survey, visited these in an effort to determine whether or not they contained any traces of vertebrates. The results were negative. During the exploration samples were collected and studied to determine whether or not they contained any organic remains. No microfossils were found in any of the beds. The red shales of the state, however, are not uniformly barren of microfossils. One near La Salle, for example, yielded the following ostracodes: *Cavellina edmistonae* Kellet, *C. nebrascensis* (Geinitz), *C.* cf. *fittsi* Kellet—young molts, *Bairdia marmorea* Kellet, *B. hoxbarensis* Harlton, and *Cytherella symmetrica* Payne. In addition, there are numerous fragments of conodonts and small echinoid spines. This particular red shale is clearly marine. The lack of microfossils in some red deposits such as those in the area around Oakwood and the presence of terrestrial forms in some concentration in the Oakwood bone bed suggest that some of the red beds may be, in part at least, nonmarine.

The resemblance of the red shales of central Illinois to those of the Arroyo Formation in the Clear Fork of Baylor County, Texas, is striking. To some ex-

[1] "On the Fossil Remains of Reptilia and Fishes from Illinois," *Proc. Phila. Acad. Nat. Sci.*, Vol. XXVII (1875), pp. 404–11.

[2] "The Coal Measures Amphibia of North America," *Carnegie Inst. Wash. Pub. No. 238* (1916), p. 9.

tent, as well, there is a similarity of stratigraphic sequence, although comparisons cannot be carried too far. The usual sequence in Illinois, as observed in several localities, is limestone, a foot or two thick and with marine fossils, gray shale, unfossiliferous or nearly so, red shale, gray to green shale, and a capping sandstone. This pattern varies somewhat, especially in the thickness of the various members. The upper sandstone may be absent and the gray shale may grade into a calcareous member and then into pure limestone. A somewhat similar sequence is encountered in the Mabelle limestone and the overlying basal Arroyo beds north of Mabelle, Texas. The fossiliferous limestone is followed by gray shales which pass into red shale. Here, however, the resemblance ends, for the red shales, varied by the presence of channel sandstones and fine conglomerates, lenticular masses of sandstone and windblown sands, persist. They clearly represent terrestrial conditions which appear to have been introduced with the deposition of the red shales. Whatever terrestrial conditions may have existed in Illinois during the deposition of the red shales were short lived, for there is rapid return to marine conditions with deposition of new limestones. At the Oakwood locality the sequence, which includes red beds, is repeated twice in a section about 40 feet thick.

In the Arroyo red beds, large areas are totally unfossiliferous and fossils commonly occur in pockets. The Oakwood locality suggests that Illinois may be similar, with the added difficulty that the vertical range of the red members is limited. If this is the case, it may be anticipated that additional pockets of vertebrates may someday be found in the red beds and associated gray shales of the state. That possibility hinges primarily upon how much of the red shale was deposited under nonmarine conditions. At present this cannot be determined with any degree of certainty.

CHANNEL SANDSTONES

As a rule it is difficult to be absolutely certain that the sandstones commonly called channel fills were actually deposited under stream conditions. There is, in addition, some difficulty in determining whether these deposits were made by water flowing on the land or in shallow marine waters. The following criteria aid in these determinations: the bedding of the sandstone is irregular; the lateral extent of the beds is limited; there are conglomeratic lenses in some of the deposits; marine invertebrates occur in some of the sandstones; fresh-water fish have been encountered in all cases where vertebrates have been found; marine shark teeth have been found in at least one of the channels. These facts strongly suggest running water, and the limited lateral extent suggests localization in a channel. The rather uncommon marine fossils give some indication of deposition under marine conditions, but it is entirely possible to explain them as erratics derived from pre-existing marine deposits which have played a part in the formation of the channel deposits.

As yet it has been impossible to trace any one of the vertebrate-bearing sandstones sufficiently far to demonstrate by shape alone that it is a channel deposit, but, in view of the nature and relationships of the materials, the conclusion seems inescapable. The deposit at the Falmouth locality (see p. 290) lies directly on a limestone, the massive sand of the channel being separated from the limestone by about three inches of soft, sandy shale. The Salt Fork deposit (see

p. 296) rests on a typical gray Pennsylvanian shale. In both cases there is a sharp break between the underlying bed and the supposed channel deposit. In both cases the contact between the two beds is irregular and gives definite evidence of an erosional unconformity. Other channels which have been visited are similar in nature but have not yielded vertebrate remains. The extensive channels represented by the Pleasantview sandstone have not as yet been thoroughly explored for vertebrates, but no remains have been reported from them.

Vertebrate remains are not scattered at random through the channels, for much of the sandstone is barren. The thin, shaly layer at the base of the Falmouth Channel carries most of the remains found at this locality, but some bones occur in the lower part of the more massive overlying sandstone. In the Salt Fork Channel the vertebrate fragments have come only from a lenticular, semiconglomeratic mass near the base of the deposit.

BLACK CARBONACEOUS SHALES

The black carbonaceous shales of the coal measures have been discussed fully in many papers and merely need to be mentioned in this report. The invertebrate fauna which they contain is not a typical marine fauna, for it contains *Orbiculoidea* and conodonts and reflects somewhat unusual conditions of deposition. Many of the shales contain abundant fish remains, among which *Petrodus*, *Lystracanthus*, and *Edestus* predominate. These three types, which may not be generically distinct, are present in other deposits which have been interpreted as originating in brackish waters. No tetrapods have been found in the black shales. One lung-fish tooth, *Proceratodus carlinsvillensis* Romer and Smith, is reported to have come from black shale, but the matrix of the specimen suggests that it was in an impure coal. This is noted under the discussion of occurrences in coal.

GRAY SHALES

Most of the gray shales in the Pennsylvanian of Illinois appear to be marine and many of them carry marine invertebrates. Some which are closely associated with coal, such as those in the vicinity of Mazon Creek, carry nodules which enclose remains of fresh-water and terrestrial animals. A limited number yield nonmarine vertebrates deposited under other conditions. Two such localities are discussed in this paper, one on Piasa Creek, Jersey County, and a second in Marion County. There are no known sedimentological characteristics of these shales which indicate whether they are marine or nonmarine, so that fossils alone form the basis for determination. In the Piasa Creek locality organic remains are preserved for the most part in phosphatic nodules. Supposedly fresh-water fish are represented by rhipidistians, whereas the remaining vertebrates are sharks of the types which occur in the black fissile shales and marine limestones. A single specimen of *Xenacanthus* was obtained by J. M. Weller from the Marion County locality. It came from a gray shale rich in plant remains.

COAL

The richest fauna of Pennsylvanian vertebrates in the United States has come from a cannel coal at Linton, Ohio. No comparable localities have been found in the state of Illinois. Near Peoria, in "Coal Number 4" of the lowest McLeansboro age, there has been found the cranial roof and a tooth of *Sagenodus*

serratus (Newberry).[3] This deposit has yielded nothing more, perhaps more because of lack of study of the coal as it was mined than because of an actual lack of preserved vertebrates. A highly carbonaceous shale at Carlinsville, Illinois, which, from the matrix on the specimen, appears to be closer to coal than to shale, has yielded the holotype of *Pr. carlinsvillensis* Romer and Smith.[4] Both of these specimens were collected prior to 1900 and are part of the Gurley collection at Walker Museum. For the most part, the coals of Illinois have not furnished much information concerning the coal-swamp vertebrates of the Pennsylvanian.

THE LOCALITIES AND THEIR FAUNAS

In the following pages important localities in the state are described, and particular attention is paid to the faunas which have come from them. Where necessary, additional information concerning modes of occurrence is presented. It will be noted that the differences in faunas appear to be primarily a function of the environments of deposition.

THE OAKWOOD LOCALITY

This locality, variously called the "Danville locality," the "Vermilion County locality," and the "Oakwood locality," lies along the northern margin of Horseshoe Bend of the Vermilion River in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$, Sec. 23, T. 19 N., R. 13 W. of Vermilion County, Illinois. The general nature of the deposits has been discussed on pages 282 and 283.

[3] A. S. Romer and H. J. Smith, "American Carboniferous Dipnoans," *Jour. Geol.*, Vol. XLII (1934), p. 710.

[4] *Ibid.*, pp. 714–16.

E. C. Case,[5] in a report on this locality summarizing the work of E. D. Cope,[6, 7, 8] lists ten genera and twenty-two species of fish, amphibians, and reptiles as follows:

Fish
- *Janassa strigilina* Cope
- *J. gurleyana* Cope
- *Pleuracanthus quadriseriatus* (Cope)
- *P. gracilis* (Newberry)
- *P. compressus* (Newberry)
- *Thoracodus emydinus* Cope
- *Sagenodus vinslovii* (Cope)
- *S. vabasensis* (Cope)
- *S. gurleyanus* (Cope)
- *S. pusillus* (Cope)
- *S. fossatus* (Cope)
- *S. heterolophus* (Cope)
- *S. paucicristatus* (Cope)
- *Peplorhina arctata* Cope

Amphibians
- *Cricotus heteroclitus* Cope
- *Cr. gibsoni* Cope
- *Cr.* sp.
- *Diplocaulus salamandroides* Cope
- *Lysorophus tricarinatus* Cope

Reptiles
- *Clepsydrops colletii* Cope
- *Cl. pedunculatus* Cope
- *Cl. vinslovii* Cope
- *Archaeobelus vellicatus* Cope

This list may be taken as a point for departure in consideration of the fauna of this pocket, for it represents the first in which the animals were listed together. Earlier names, applied to certain of the genera, and Cope's revisions of the first-given names may be found in Cope's papers of 1875 and 1877. Various writers dealt with particular specimens between

[5] "The Vertebrates from the Permian Bone Bed of Vermilion County, Illinois," *Contr. Walker Mus.*, Vol. I (1901), pp. 3–29.

[6] Pp. 404–11 of ftn. 1 (1875).

[7] "On the Vertebrata of the Bone Bed of Eastern Illinois," *Proc. Amer. Phil. Soc.*, Vol. XVII (1877), pp. 53–64.

[8] "Descriptions of Extinct Vertebrata from the Permian and Triassic of the United States," *Proc. Amer. Phil. Soc.*, Vol. XVII (1877), pp. 182–93.

1875 and 1901, but few fundamental modifications of Cope's earlier determinations were made. Since 1901 others have considered the fauna as a whole or in part. The tendency has been to reduce the number of genera and species.

L. Hussakof[9] considered the fish in some detail. He retained the two species of *Janassa* on the grounds that their identity could not be demonstrated, since the two type-teeth, *J. strigilina* (W. M. 6500) and *J. gurleyana* (W. M. 6501), were from different parts of the mouth. There seems, however, no valid reason for assuming the two to be different, since it is now known that variation of the teeth in a single species is greater than that between these two. Both teeth may be referred to the first-named species *J. strigilina*. *T. emydinus* was considered by Hussakof as too incomplete to stand as the type of a genus. It appears to be a specimen of *Janassa* whose species cannot be determined.

A study of the three species referred by Case to the genus *Pleuracanthus* leads to a somewhat vexing taxonomic situation. Cope originally designated two sets of spine fragments as *Orthacanthus quadriseriatus* and *O. gracilis*. He referred a series of small teeth to *Diplodus* (?)*compressus* (Newberry). He was of the opinion that the teeth might actually belong to one of the species of *Orthacanthus*. This group at best is certain to lead into taxonomic difficulties because specimens are known variously from teeth, spines, parts of chondrocrania, and parts of the postcranium. It demonstrated, however, early in the history of the group that certain types of teeth and spines were associated, and failure to take cognizance of this early work has lead into more trouble than was necessary. The literature concerning Cope's specimens, as well as many others, is confusing.

Cope,[10] in 1883, replaced the name *Diplodus* with a new generic name *Didymodus* on the basis that *Diplodus* was preoccupied. Case,[11] in 1901, clarified the situation by referring all of the species from Oakwood to the genus *Pleuracanthus* Agassiz. The name of *Pleuracanthus* as applied to this type of shark by L. Agassiz[12] in 1837 is, however, invalid since it was preoccupied by *Pleuracanthus* Gray,[13] a generic name given to three species of Brazilian beetles in 1832. E. Beyrich,[14] in 1848, considered specimens of *Pleuracanthus* Agassiz and *Orthacanthus* Agassiz and other related types at some length. Inasmuch as he gave an adequate description of the genus *Xenacanthus*, which he proposed in this paper with *X. decheni* (Goldfuss) as his genotype, and also recognized the identity of *Pleuracanthus* Agassiz and *Xenacanthus*, his name may be considered to be valid and to replace *Pleuracanthus* (see O. P. Hay.)[15] Thus Cope's three species, if Case's lead in considering them generically identical be followed, may be called *X. ?compressus* (New-

[9] "Discussion of the Fossil Fishes," in E. C. Case, "Revisions of the Amphibia and Pisces of the Permian of North America," *Carnegie Inst. Wash. Pub. No. 146* (1911), pp. 155–75.

[10] "On some Vertebrates from the Permian of Illinois," *Proc. Phila. Acad. Nat. Sci.*, Vol. XXXV (1883), p. 108.

[11] Ftn. 5 (1901).

[12] *Recherches sur les Poissons Fossiles*, Vol. III (1837), p. 66.

[13] E. Griffith-C. Cuvier, *The Animal Kingdom* (London: Whitaker, Treacher & Co., 1832), Vol. XIV, p. 172.

[14] "Ueber *Xenacanthus Decheni* und *Holacanthus gracilis*, Zwei Fische aus der Formation des Rothliegende in Nord-Deutschland," *Arch. Min. Geogn. Bergb.*, Vol. XXII (1848), pp. 646–54.

[15] "Second Bibliography and Catalogue of the Fossil Vertebrata of North America," *Carnegie Inst. Wash. Pub. No. 390*, Vol. I (1929), p. 537.

berry), since Newberry's genus *Diplodus* must be replaced by *Xenacanthus, X. quadriseriatus* (Cope) and *X. gracilis* (Newberry). While this resolves the case of the Oakwood species, it does not clarify the status of various other genera and species of the *Xenacanthus* group.

In 1884, Cope[16] described as *Didymodus* a specimen from the Permian of Texas consisting of a chondrocranium. He apparently referred it to Newberry's species *Dip. compressus* (Newberry). S. Garman,[17] in 1885, in a paper in which he pointed out among other things that Cope's specimen clearly was not congeneric with his genus *Chlamydoselachus* as Cope had suggested, said that *Didymodus* was a synonym of *Xenacanthus* and thus invalid. He further stated that Cope's specimen was not *Xenacanthus*, as Cope himself (using the name *Pleuracanthus*) had intimated. Garman proposed the name *Diacranodus* and recognized the species *Dia. compressus* and *Dia. platypternus*. His procedure in using the specific name *compressus*, which appears to be a retention of the name as originally used in *Dip. compressus* Newberry, is questionable. If *Didymodus*, which replaced *Diplodus*, is a synonym of *Xenacanthus*, then Newberry's species must be referred to *Xenacanthus*. Garman indicates, following Cope, that *Diacranodus*, his new genus, is not the same as *Xenacanthus*. Had Garman indicated that he was naming a new species of the genus *Diacranodus* and had any description or definition of the species been given, the species might be acceptable. But Garman did neither. Cope,[18] in 1890, proposed the specific name *texensis* for the Texas specimen to replace *compressus* as used in *Did. compressus* (Newberry) and in *Dia. compressus* (Newberry). This species may be considered as valid replacing *Dia. compressus* as used by Garman. Whether the species is to be referred to *Xenacanthus*, on the basis that *Didymodus* is a synonym of *Xenacanthus*, or to *Diacranodus* must be determined by morphological comparisons.

The generic name *Diacranodus* may be considered valid if the generic separation from *Xenacanthus* can be demonstrated. Hussakof[19] accepted the name, indicating that the differences in the chondrocrania of *Xenacanthus*, for which he used the name *Pleuracanthus*, and *Diacranodus* are sufficient to make the separation valid. In essence this separates the Texas Permian specimens from these of the Carboniferous and earlier deposits. It is not, however, entirely satisfactory, since it is necessary to compare chondrocrania to determine the genus to which various specimens belong and only in rare instances is this possible. Furthermore, the differences in chondrocrania are slight and of questionable value for generic separation. Differentiation on the basis of teeth and spines is not feasible with the materials now known, and it seems improbable that teeth, at least, will ever furnish an adequate basis. This is true not only for specimens referred either to *Diacranodus* or *Xenacanthus* but also for various other named genera, *Protodus* Woodward, *Thrinacodus* Newberry, *Compsacanthus* Newberry, *Doliodus* Traquair, *Dittodus* Owen, *Orthacanthus* Agassiz, and others. It is true that teeth referred to various genera

[16] "The Skull of a Still Living Shark from the Coal Measures," *Amer. Nat.*, Vol. XVIII (1884), pp. 412–13.

[17] "*Chlamydoselachus anguineus* Garm.—a living species of Cladodont shark," *Bull. Mus. Comp. Zoöl.*, Vol. XII (1885), pp. 1–35.

[18] *Trans. Amer. Phil. Soc.*, new ser., Vol. XVI (1890), p. 285.

[19] P. 159 of ftn. 9 (1911).

in some instances show differences which might reflect generic distinctions, but a survey of the literature shows the confusion of reference which has occurred, indicating that in many instances definitive characters were at best vague.

Since generic differentiation on the basis of teeth and spines is unsatisfactory and since the differences between other characters of known specimens are not great, a practical working basis can be established by referring all these related forms from the Devonian through the Permian to a single genus *Xenacanthus* Beyrich. In so doing it must be realized that this genus contains a large and somewhat varied series and that the genus is not entirely commensurate with many genera defined on the basis of more adequate materials. But, under the circumstances, it is the only procedure which establishes a working basis for differentiation of the various xenacanthid sharks. In no case are the differences between known parts of the fishes sufficiently great that such an assignment does real violence to the concept of the genus. Throughout the pages of this paper we shall use this scheme of reference to and differentiation of the xenacanthids.

Hussakof,[20] in 1911, indicated that *T. emydinus*, which Woodward has called an incomplete tooth of *Janassa*, is too fragmentary to stand as a valid genus. The specimen is lost, but the illustrations show that Hussakof was entirely justified in his stand.

Case[21] referred all the lungfish of the Oakwood locality to the genus *Sagenodus*, following S. Woodward's[22] work of 1891. Cope originally recognizes the genera *Ctenodus* and *Ceratodus*. Romer and Smith,[23] in 1934, referred all specimens, originally differentiated into seven species, either to *S. serratus* or *S. paucicristatus*. The latter species is represented by one tooth, more elongated than the rest. Romer and Smith expressed the opinion that it is close to *S. copeanus* (Williston) and *S. porrectus* (Cope).

Cope[24] described a small tooth-studded plate (W. M. 6511) under the name of *Pe. arctata*. That a specimen so fragmentary should have been made a genotype is somewhat unfortunate. Cope first referred it to the Crossopterygia and later[25] called it a thermorphous reptile. Case,[26] while suggesting the possibility of cotylosaurian affinities, used a second specimen for comparison and concluded that the relationships were with the Crossopterygia. Hussakof[27] compared *Pe. arctata* with Fristch's genus *Sphaerolepis*. He concluded that *Peplorhina* and *Sphaerolepis* were synonymous and that *Sphaerolepis* should be retained in spite of the fact that *Peplorhina* had priority because *Peplorhina* was an insufficiently described genus. If his determination of synonymy is correct, as it would seem to be on the somewhat inadequate basis of Cope's specimen, his procedure appears the best to follow. The name *?Sphaerolepis arctata* is used in the revised faunal list in this paper with the reservation that the generic identity of Cope's specimen has not been positively established.

[20] *Ibid.*, p. 157.

[21] Pp. 8–12 of ftn. 5 (1901).

[22] *Catalogue of the Fossil Fishes in the British Museum*, Part II (1891), pp. 261–62.

[23] Pp. 706–10 of ftn. 3 (1934).

[24] P. 54 of ftn. 7 (1877).

[25] "Third Contribution to the History of Vertebrata of the Permian Formation of Texas," *Proc. Amer. Phil. Soc.*, Vol. XX (1882), pp. 394–95.

[26] Pp. 12–13 of ftn. 5 (1901).

[27] Pp. 170–71 of ftn. 9 (1911).

Cope[28,29] named two species of the amphibian *Cricotus*. There is no adequate basis for differentiating the two. They occur in the same deposit, are similar in size, and were called distinct species primarily because the remains were from different parts of the skeleton. In the revised faunal list all remains of *Cricotus* from the Oakwood locality are referred to the first-named species, *Cr. heteroclitus* Cope.

The genotype of *Diplocaulus*, a genus now much better known from the Texas Permian, came from the Oakwood locality. The genus was based upon several vertebrae (W. M. 6513, 6514, 6515, 6516). Although Cope first assigned these vertebrae to the Pelycosauria, he shortly recognized their amphibian affinities. Only a single species, *Diploc. salamandroides* Cope, was named. The species is valid, but reference of specimens from other localities to it is difficult because the vertebrae lack features which are clearly diagnostic at the species level.

L. tricarinatus Cope, the only recognized species of this genus, was described from the Oakwood locality on the basis of vertebrae.[30] The multitude of specimens known from the Permian of Texas have been referred to the species. The nature of the type specimens, poorly preserved vertebrae (W. M. 6525 the holotype, and 6527, 6528, paratypes), make it uncertain that this reference is correct. Furthermore, there clearly is more than one species of *Lysorophus* from the Texas red beds although as yet specific names have not been given.[31]

[28] Pp. 404–11 of ftn. 6 (1875).

[29] P. 186 of ftn. 8 (1877).

[30] *Ibid.*, p. 187.

[31] E. C. Olson, "The Fauna of the *Lysorophus* Pockets in the Clear Fork Permian, Baylor County, Texas," *Jour. Geol.*, Vol. XLVII (1939), pp. 394–95.

A. S. Romer and L. I. Price[32] referred all the reptilian remains, designated by Cope as three species of *Clepsydrops* and one of *Archaeobolus*, to two of Cope's original species *Cl. colletii* and *Cl. vinslovi*. *Cl. colletii* includes the large forms and *Cl. vinslovi* the small ones. No important morphological differences, other than size, have been found between the two. S. W. Williston[33] described a specimen as *?Captorhinus illinoisensis*. Romer and Price state that this specimen shows no difference from *Cl. vinslovi* and that it is to be referred to that genus and species. No cotylosaurs are known from this deposit, the only reptile being *Clepsydrops*, a primitive pelycosaur which is unknown from any other locality.

On the basis of the revisions cited above, the faunal list of the Oakwood locality is as follows:

Class Chondrichthyes
  Subclass Elasmobranchii
    Order Xenacanthodii
      Family Xenacanthidae
        X. ?compressus (Newberry)
        X. gracilis (Newberry)
        X. quadriseriatus (Cope)
  Subclass Holocephali
    Order Bradydonti
      Family Petalodontidae
        J. strigilina Cope
Class Osteichthyes
  Subclass Choanichthyes
    Order Dipnoi
      Family Ctenodontidae
        S. paucicristatus (Cope)
        S. serratus (Cope)
  Subclass Actinopterygii
    Superorder Chondrostei
      Order Palaeoniscoidea
        Family Trissolepidae
          ?Sp. arctata (Cope)
Class Amphibia
  Subclass Apsidospondyli
    Superorder Labyrinthodontia

[32] "Review of the Pelycosauria," *Geol. Soc. Amer. Spec. Papers No. 28* (1940), pp. 212–15.

[33] *American Permian Vertebrates* (Chicago: University of Chicago Press, 1911), p. 69.

Order Embolomeri
Family Eogyrinidae
Cr. heteroclitus Cope
Subclass Lepospondyli
Order Microsauria
Family Lysorophidae
L. tricarinatus Cope
Order Nectridia
Family Keraterpetonidae
Diploc. salamandroides Cope
Class Reptilia
Subclass Synapsida
Order Pelycosauria
Family Ophiacondontidae
Cl. colletii Cope
Cl. vinslovi Cope

THE FALMOUTH LOCALITY

THE DEPOSIT

The most productive channel deposit so far found in the Illinois Pennsylvanian is located in the center SW. ¼, Sec. 15, T. 7 N., R. 3 E., about 3½ miles southeast of Falmouth, in Jasper County. This locality was called to the writer's attention by Professor J. Marvin Weller of the Department of Geology, the University of Chicago. A moderately large collection of vertebrate specimens has been obtained in the course of three visits to it.

The beds are exposed in an abandoned road-cut. The total thickness of the vertebrate-bearing deposit is about two feet. It lies on an irregularly eroded, massive marine limestone and is overlaid by an unfossiliferous gray shale. The channel lies high in the Illinois Pennsylvanian, but its precise age has not been determined.

The channel appears to have trended east-west at right angles to the direction of the road. Quarrying operations followed the deposit from its northern limit, south for about 15 feet, at which place the beds pinched out. The lower part of the deposit is composed of a thin-bedded sandstone with shaly partings and the basal three or four inches are composed of sandy shale. In places throughout the lower part of the deposit are lenses of clay pebble conglomerate similar to those found at the Salt Fork locality (see p. 296).

Remains of vertebrates and invertebrates occur throughout the deposit, but the greatest concentrations are in the shaly partings between the sandstone and conglomeratic slabs. The bones and teeth are scattered, and there is little or no association of skeletal parts. As a result, most specimens are fragmentary. The bones are oriented with their long axes in the horizontal plane, parallel to the bedding, but there is no alignment indicating current direction. Invertebrates, all microscopic in size, are found throughout the deposit, but they occur in high concentration in small lenses. Bones and invertebrates are found intermixed. Some layers are composed almost exclusively of ostracodes, worm tubes, and small flakes of bone.

THE FAUNA

The following vertebrates have been identified from the Falmouth locality:

Class Chondrichthyes
Subclass Elasmobranchii
Order Cladoselachii
Family Ctenacanthidae
Ctenacanthus cf. *marshi* Newberry
Order Xenacanthodii
Family Xenacanthidae
X. cf. *latus* (Newberry)
X. gracilis (Newberry)
Class Osteichthyes
Subclass Choanichthyes
Order Dipnoi
Family Ctenodontidae
Sagenodus sp.
Family Ceratodontidae
Pr. cf. *carlinsvillensis* Romer and Smith
Class Amphibia
Subclass Apsidospondyli
Superorder Labyrinthodontia

Order Rhachitomi
Family Eryopidae
Genus indeterminate
Subclass Lepospondyli
Order Microsauria
?Family Gymnarthridae
Genus indeterminate

Description of the vertebrates.—Identification of many of the specimens has been made difficult by their fragmentary nature. For this reason, a rather detailed description of the specimens identified in the faunal list as well as a few other specimens whose affinities are uncertain are given in the following paragraphs.

Ctenacanthus cf. *marshi* Newberry

One specimen consisting of an excellently preserved lower part of a fin spine and one poorly preserved partial fin spine are tentatively referred to this species. The specimens show no differences from the type of *Ct. marshi* figured by J. S. Newberry,[34] but the characters are such that it is difficult to be certain of specific identity. *Ctenacanthus* spines occur in typical marine rocks of Devonian and Mississippian age and there are numerous marine occurrences in the Pennsylvanian. There are, however, various reports which suggest that *Ctenacanthus* also may have lived under nonmarine conditions during the late Carboniferous and the Permian. Various spines have been reported from the "coal measures." It is not indicated in these reports whether the specimens came from marine or nonmarine phases of these beds, but the implication in some instances is that they are nonmarine. A specimen has been reported from the Permian of Texas (see Hussakof). This is presumably from the red beds. The specimens from the Falmouth locality came from beds which appear to be nonmarine, judging from the associated vertebrates. There is, of course, no conclusive evidence that they were not carried in from a site of earlier deposition, but they are little worn and give no indication that they were deposited in another type of matrix. The preservation is precisely that characteristic of all bones in the deposit, and the interstices of the bone are filled with fine material of the matrix in which it was found. The implication that the specimens represent a case of primary deposition is very strong. If this is the case, they give additional evidence that *Ctenacanthus* had both a fresh and salt-water habitat during the late Carboniferous.

[34] *Geol. Surv. Ohio*, Vol. I, Part II (1873), pp. 326–28, Pl. 35.

Xenacanthus cf. *latus* (Newberry)
(Fig. 1, *D*)

Numerous teeth and fragments of calcified cartilage represent this species in the collection. The teeth correspond closely in all respects to the type of the species described by J. S. Newberry.[35] They are large, with broad, divergent spines. The central tubercle is either small or absent. As would be expected, there is considerable size range in the specimens. Some of the smaller ones more nearly resemble *X. gracilis* (Newberry), and there is some indication that these two "species" may intergrade. Associated with some of the large teeth and scattered through the sandstone are fragments of calcified cartilage which appear to pertain in part to this species on the basis of their size and proximity to the teeth. No details of structure are shown by the cartilage.

Xenacanthus gracilis (Newberry)
(Fig. 1, *C*)

Many small teeth have been referred to this species. The base of the teeth is

[35] *Ibid.*, p. 326.

small and the lateral denticles are long, divergent toward the points, and not compressed. The central denticle is moderately developed. Differentiation of this species from *X. compressus* is based on slight differences of shape and crenulation of the lateral denticles. It is entirely possible that the two are not distinct. The reference of the Falmouth specimens to *X. gracilis* is based on the lack of compression of the denticles and their lack of serration.

Order Dipnoi: Remains of lungfish constitute the major part of the fossils found in the deposit. They consist of three moderately well-preserved tooth plates, an abundance of skull plates and scales, and many ribs which are tentatively assigned to this group. The only parts upon which diagnosis can be based are the teeth. The skull bones are separated and none are diagnostic.

Proceratodus cf. *carlinsvillensis* Romer and Smith

(Fig. 1, *A*)

Two large tooth plates (W. M. 1799, 1800) appear to pertain to the genus *Proceratodus* erected by Romer and Smith[36] to receive *Ceratodus*-like Paleozoic dipnoans. In neither tooth is the inner margin clearly seen, so that comparisons of this critical area are impossible. The best-preserved tooth plate is W. M. 1799. It is a pterygoid plate which has many features in common with the holotype of *Pr. carlinsvillensis*. The specimen measures 50 mm. in length and is set with heavy ridges with a very slight tuberculation on the second ridge only. In the presence of this slight tuberculation the plate differs from that of *Pr. carlinsvillensis*, upon which no tubercula-

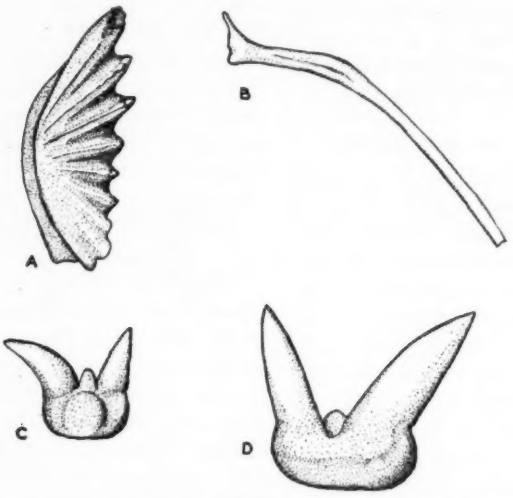

FIG. 1.—Fish remains from the Falmouth locality. *A*, Pterygoid plate of *Proceratodus* cf. *carlinsvillensis* Romer and Smith, W. M. 1799, ×⅔; *B*, rib, tentatively referred to dipnoans, ×⅔; *C*, inner aspect of tooth of *Xenacanthus gracilis* (Newberry), ×2; *D*, outer aspect of tooth of *Xenacanthus* cf. *latus* (Newberry), ×1.

[36] Pp. 706–10 of ftn. 3 (1934).

tion seems to be developed. There are seven strong ridges in the specimen, but, unlike the holotype of the species, there are two faint additional ridges. All the ridges differ from those of the holotype of *Pr. carlinsvillensis* in that they carry slightly farther toward the external margin of the plate. The second specimen (W. M. 1800) confirms this last observation but, unlike the first, shows no tuberculation on any ridge. It is not complete enough to allow a count of the ridges. These two specimens are close to *Pr. carlinsvillensis*, but they differ in minor respects, one of which—the number of ridges—Romer and Smith have suggested as a basis for specific differentiation. It is probable that the specimens will prove to represent a different species, but the writer feels that they cannot be considered adequate for erection of a new species until more data on the range of variation within the genus are available.

Sagenodus sp.

One tooth plate (W. M. 1801) differs markedly from the two just described in that the ridges are strongly tuberculated. It appears to be a mandibular plate. Only the outer portion of the specimen is preserved. This shows seven strong ridges, and a somewhat weathered posterior area probably accommodated three or four more. The specimen is referable to the genus *Sagenodus*, but its preservation is such that specific assignment is not possible. It resembles *S. serratus* in all features except size. It is larger than any described specimen of this species, the length being about 47 mm. It appears to be about the size of plate which might be expected in *S. ohioensis* (Newberry), but, as only the skull of this species is known, no direct comparison is possible.

It is not possible to assign the plates, scales, and ribs of the deposit to a genus among the Dipnoi. The well-preserved skull elements closely resemble those of *S. serratus*, but they are considerably larger. The most abundant vertebrate remains in the deposit are long, heavy, curved ribs (Fig. 1, *B*). They are circular in cross section in the shaft and have a rather narrow single head. Their abundance suggests that they are associated with the lungfish. They do not belong to the amphibian represented by vertebrae, since the heads are not suitable for articulation on the broad transverse processes.

Amphibia: There are numerous fragments of amphibians in the deposit but relatively few are well enough preserved to be identified. Much of the material seems to pertain either to a moderately large form assigned to the Eryopidae or to a very small form tentatively referred to the Gymnarthridae.

Family Eryopidae

A number of fragments which represent a moderately large amphibian have found scattered in the channel sand. Just enough is preserved to be intriguing. Best preserved is a spine and arch of a vertebra (W. M. 1802) (Fig. 2, *A*). Two partial spines of the same species have been found, but they add little to the details determined from the one specimen. In addition, there is a very poorly preserved fragment of a lower jaw and one of part of a pelvis. There are other fragments of bone which may belong to this amphibian, but they are so broken that no guess concerning their identity is possible. There is no assurance that these various parts belong to the same species or even the same genus, but all seem to pertain to animals of about the same size

and the same general type. It is possible that they are actually fragments of one individual.

The well-preserved vertebra is most definitive. It consists of a spine, a neural arch with two zygapophyses, and one complete transverse process. The spine, which is 37 mm. high, is topped by a quadrilateral, rugose surface. The spine has been compressed but clearly shows a roughly ridged lateral surface

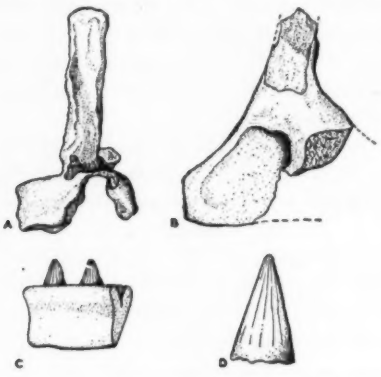

FIG. 2.—Amphibian remains from the Falmouth locality. *A*, Anterolateral aspect of vertebral spine and arch of an eryopid, W. M. 180½, ×½; *B*, partial pelvis tentatively identified as eryopid, ×½; *C*, section of lower jaw tentatively identified as eryopid, ×1; *D*, labyrinthine tooth pertaining either to Amphibia or Crossopterygia, ×½.

much like that of *Eryops*. The neural arch is narrow and the zygapophyses are strongly inflected. The transverse process is long and terminates in a single, broad facet for the rib head. In all these features the vertebra is like one of *Eryops*. It differs principally in size and proportion. No mature specimen of *Eryops* is so small as the specimen under consideration, and in none is the spine so long in proportion to the other dimensions. The vertebra, while resembling those of *Eryops*, certainly belongs to another genus, but the specimen is not adequate for a valid definition of the genus.

A fragment of lower jaw, about 50 mm. long, is another indication of a moderately large amphibian. Several teeth are visible (Fig. 2, *C*), and they alone give some indication of the relationship of the specimen, since the jaw itself is poorly preserved and cannot be satisfactorily cleared of matrix. The teeth measure about 4 mm. in height and are broad basally, measuring about 2 mm. longitudinally. They taper to a sharp point. The crowns are ridged, suggesting a highly developed labyrinthine structure. The teeth are in general *Eryops*-like but, like the vertebra, cannot be considered as pertaining to that genus. The vertebra and jaw lay about 1 foot apart in the same bed of the deposit, suggesting that they, with the pelvis which was close by, may have come from the same animal.

The partial pelvis (Fig. 2, *B*) consists of the ischium and a small part of the ilium and pubis. It is clearly that of a tetrapod and is of about the size to be anticipated in an animal with the vertebra described above. There is, however, nothing definitive to suggest that the two belong to the same species or even, for that matter, that they are to be placed in the same family.

One other specimen may be mentioned in connection with this suite of amphibian remains, a large labyrinthine tooth which must represent an animal unknown from any other fragments in the deposit (Fig. 2, *D*). The tooth is conical and measures about 31 mm. in height. It is much like the large palatal teeth of *Eryops* but is not unlike homologous teeth in certain large crossopterygians. It may belong to either the amphibians or the crossopterygians.

?Family Gymarthridae

Two small lower jaws, a fragment of a snout with five teeth, a small skull plate, and various other fragments are thought to belong to the Gymnarthridae. One of the lower jaws (W. M. 1803), which consists of part of the ramus carrying four teeth (Fig. 3, *A*), is moderately well preserved. The jaw measures 6.2 mm. in length, and the four preserved teeth form a row 4.1 mm. long. The teeth are rather bulbous, as in most gymnarthrids, but are moderately long and pointed. The highest has a crown length of 2.1 mm., and the shortest is just under 1 mm. These teeth show strong resemblances to those of the gymnarthrids and are the principal basis for assignment of the specimens to this family. Admittedly, such reference is not based on the sort of evidence which can be considered conclusive.

The teeth in the fragment of snout are very much like the corresponding teeth in *Euryodus* and many well represent a related genus (Fig. 3, *B*). Several small skull plates which are deeply sculptured may belong to the same type of animal, but in none are there definitive characters which validate this suggested relationship.

Description of the invertebrates.—Many parts of the channel deposits are rich in microscopic invertebrates. Some small pockets are composed almost exclusively of thin-shelled, simple ostracodes. Worm tubes are mixed with the ostracodes and occur scattered throughout all parts of the sandstone, clay, and conglomerate. The ostracodes all appear to belong to two genera, *Cavellina* and *Cytherella*. Specific determinations, difficult in these genera, have not been attempted. These two genera were also noted from the red horizon near La Salle, Illinois. No representatives of the genus *Bairdia* occur at Falmouth. The species of *Cavellina* and *Cytherella* from the Falmouth locality appear to be different from those identified in the red deposit. The tests are thinner and more subject to crushing. The worm tubes all appear to belong to a single species, *Spirorbis anthrocosia*, which is characteristic of the Pennsylvanian.

Discussion of the fauna.—Both the vertebrates and the invertebrates point to fresh-water origin of the Falmouth deposit. The only element suggesting marine origin in the shark *Ctenacanthus*, whose occurrence has been discussed earlier. The vertebrate fauna, although composed of fragmentary specimens, is of interest in showing an assemblage different from that found in typical coal-swamp deposits. The only comparable fauna in the Pennsylvanian of Illinois is that found at the Oakwood locality. Both of these faunas give evidence of a primitive, "red beds" type of fauna, which should throw some light upon the development of the better known faunas of the Dunkard, Abo, Wichita, and Clear Fork when better-preserved remains are discovered. In both localities, Falmouth and Oakwood, there are fishes which are related to the xenacanthids and dipnoans of the lower Permian. There appears to have been little change in these groups between the Pennsylvanian and the

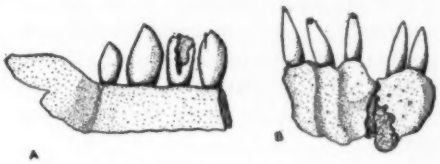

FIG. 3.—Amphibians from the Falmouth locality. *A*, Lower jaw tentatively referred to the Gymnarthridae, ×5; *B*, fragment of snout tentatively referred to Gymnarthridae, ventral aspect, ×5.

Permian. Among the amphibians there is evidence of at least four groups well known in the Permian; the Embolomeri, in *Cricotus* of Oakwood; the Rhachitomi, in the eryopid from Falmouth; the Microsauria, in the small gymnarthrid from Falmouth; and the Lysorophia, in *Lysorophus* from Oakwood. Among the reptiles, the only known genus is *Clepsydrops*, a primitive pelycosaur, from Oakwood. It is interesting to note that no cotylosaurs have been found in the Pennsylvanian of Illinois. It seems certain that they were in existence at the time of the formation of the deposits. Their absence probably is to be accounted for merely by accident of preservation, or it may be that they lived in a somewhat different environment from that of any of the types which are preserved.

SALT FORK LOCALITY

Just south of the Salt Fork branch of the Vermilion River, along the section line between Sec. 31 and Sec. 32, T. 19 N., R. 13 W., a deep road-cut has exposed a massive, somewhat irregularly bedded, yellowish-gray sandstone about 20 feet thick. The northern end of the deposit has been destroyed by the river, but the sandstone can be followed south for 150 feet in the road-cut. The same sandstone crops out in the valley wall about 50 feet west of the highway. The sand appears to have been deposited in a channel which trended northeast by southwest, so that the road cuts it nearly at a right angle.

The stratigraphic age of this deposit, as is the case with many Pennsylvanian channels, is not entirely certain. The sandstone lies well above the Lonsdale, which is exposed near the bridge to the north of the river. Mr. George Wilson, who called the deposit to the writer's attention, suggests that it may be a La Salle equivalent.

Much of the deposit consists of a massive, thickbedded, micaceous sandstone. Near the base is a thin, fine, red-and-green layer of sand which passes laterally into a lenticular red conglomerate near the north end of the exposure. The lenticular body, which crops out on both sides of the road, and the fine sand immediately above and below it have yielded fragmentary remains of vertebrates. As in the case of the Falmouth channel, the vertebrates are associated with lenses of clay pebble conglomerate.

The remains of vertebrates obtained from this locality are all very fragmentary. The following have been identified:

Class Chondrichthyes
X. cf. *latus* (Newberry)
6 teeth and one spine
Orodus sp.
1 tooth
Class Amphibia
2 fragments of small limb bones and several fragments of skull plates or dermal armor
Labyrinthine teeth
2 specimens of small size which may pertain either to crossopterygians or amphibians

In addition to these traces of vertebrates, three brachiopods were found in close association with the vertebrate remains.

There is a clear case of mixing of marine and fresh-water species in this deposit. The conditions of origin are not entirely clear. The sandstone overlies a gray shale which appears to have been the source of the clay pebbles in the lenticular conglomerate. The marine fossils may well have been washed in from the shale or from another marine deposit. Both *Orodus* and the brachiopods are typical marine Pennsylvanian forms. They do not, however, show any evi-

dence of extensive transportation. It seems possible that the sandstone may have been developed as a shallow-water deposit under marine conditions or that it may have developed in a subaerial channel. There is little conclusive evidence for either interpretation.

MAZON CREEK AND VICINITY

The famous plant-bearing shales of Mazon Creek and the near-by strip mines have produced a considerable number of vertebrates. These have been described and discussed by many writers. Certain elements of the fauna have received close attention in recent years. The knowledge of these may be considered to be in a moderately satisfactory state. Other parts have received little attention since early studies were made. It is not the purpose of this paper to undertake detailed systematic and morphological revisions but rather to give a survey of the present knowledge of the Pennsylvanian vertebrates from Illinois. It is recognized that certain elements of the Mazon Creek fauna are in need of restudy. In the course of the following discussion, areas which are in need of reworking are indicated. It is hoped that this summary of the status of the fauna will encourage more thorough studies.

Attempts to found species on the basis of fragmentary and, in some instances, poorly preserved materials characteristic of the ironstone nodules of Mazon Creek have resulted in an unjustified multiplication of names. While a rather large number of fish specimens is known, adequately preserved amphibians probably do not number over twenty. The majority of good specimens of amphibians have been designated as holotypes. Revisions are almost certain to reduce the number of named species; this has been the case in areas where careful revisions have been made. Adequate faunal lists probably will be somewhat shorter than the one presented at the end of this section, and this list itself is considerably shorter than the earlier ones from which the faunal list which follows was prepared.

The shale bearing the fossiliferous ironstone nodules has been dated as Westphalian C–D by Darrah.[37] He suggests that they fall in G–H of Dix's system of terminology. Westoll, re-evaluating the evidence submitted by Darrah, suggests that the beds are slightly younger and should be placed in floral zone H. These correlations are based entirely on paleobotanical evidence, for the vertebrates and invertebrates have not as yet proved of value for detailed dating. Most of the vertebrates have been obtained by collectors primarily interested in the flora, and vertebrate remains are so rare that it is not feasible to collect the area solely for them.

C. R. Eastman[38,39,40] and Moodie[41] compiled faunal lists of the Mazon Creek vertebrates which will serve as bases for consideration of the fauna. The following list was drawn from these sources and shows genera and species entered in the classification in the manner of these two writers:

[37] T. S. Westoll, "The Family Hapolepidae: A New Family of Late Carboniferous Bony Fish," *Bull. Amer. Mus. Nat. Hist.*, Vol. LXXXIII (1944), p. 9.

[38] "The Carboniferous Fish Fauna of Mazon Creek, Illinois," *Jour. Geol.*, Vol. X (1902), pp. 540–41.

[39] "Some Carboniferous Cestraciont and Acanthodian Sharks," *Bull. Mus. Comp. Zoöl.*, Vol. XXXIX (1902), p. 97.

[40] "Carboniferous Fishes from the Central Western States," *Bull. Mus. Comp. Zoöl.*, Vol. XXXIX (1903), p. 194.

[41] Pp. 12–13 of ftn. 2 (1916).

Fish
- Elasmobranchii
  - *Pleuracanthus* (*Diplodus*) *compressus* (Newberry)
  - *P.* (*Dip.*) *latus* (Newberry)
  - *P.* (*Dip.*) *lucasi* (Newberry)
  - *Acanthodes beecheri* Eastman
  - *A. marshi* Eastman
  - *Campodus scitulus* (St. John and Worthen)
- Dipnoi
  - *Ctenodus* sp. undesc.
  - *Sagenodus cristatus* Eastman
  - *S. foliatus* Cope
  - *S. lacovianus* Cope
  - *S. occidentalis* (Newberry and Worthen)
  - *S. quadratus* (Newberry)
  - *S. quincuniatus* Cope
  - *S. reticulatus* (Newberry and Worthen)
  - *S. textilis* Hay
- Crossopterygii
  - *Rhizodopsis? mazonius* Hay
  - *Coelacanthus exiguus* Eastman
  - *Co. robustus* (Newberry)
  - *Co. elegans* Newberry[42]
- Actinopterygii
  - *Eurylepis* sp. indet (fide J. S. Newberry)
  - *Rhadinichthys gracilis* (Newberry and Worthen)
  - *Elonichthys disjunctis* Eastman
  - *E. hypsilepis* Hay
  - *E. perpennatus* Eastman
  - *Platysomus circularis* Newberry and Worthen
  - *Pl. lacovianus* Cope
  - *Cheirodus orbicularis* (Newberry and Worthen)

Class Amphibia
- Subclass Euamphibia
  - Order Branchiosauria
    - Family Brachiosauridae
      - *Micrerpeton caudatum* Moodie
      - *Eumicrerpeton parvum* Moodie
      - *Mazonerpeton longicaudatum* Moodie
      - *M. costatum* Moodie
  - Order Caudata
    - Suborder Proteida
      - Family Cocytinidae
        - *Erierpeton branchialis* Moodie
- Subclass Lepospondyli
  - Order Microsauria
    - Family Amphibamidae
      - *Amphibamus grandiceps* Cope
      - *Am. thoracatus* Moodie
      - *Cephalerpeton ventriarmatum* Moodie
    - Family Molgophidae
      - *Erpetobrachium mazonensis* Moodie
- Subclass Stegocephalia
  - Order Temnospondyli
    - Suborder Embolomeri
      - Family Cricotidae
        - *Spondylerpeton spinatum* Moodie

Revisions in recent years have modified the concepts of the dipnoans and of *Eurylepis* and *Rhadinichthys* among the fish and of most of the amphibians. Careful study of the other fishes is needed. The problems of the placoderms and the sharks are not serious and probably could be readily resolved. A review of the crossopterygians and the majority of actinopterygians will necessitate study of all the scattered specimens and a careful analysis which takes cognizance of recent developments in taxonomy. This will be a long and difficult task.

Even a cursory study of certain groups indicates taxonomic changes which are desirable. *Pleuracanthus* should be replaced by *Xenacanthus*. That there are three species of this genus is uncertain, but, since the determination of species based on single teeth in this genus is difficult if not impossible, the three may be retained until an adequate basis for differentiation is developed. *Acanthodes* should be replaced by *Acanthoessus*, which has priority.[43] There are two species of the genus present, but that

[42] This species is not entered in any of Eastman's lists but is suggested as being present in several papers; see, for example, "Fossil Fishes in the Collection of the United States National Museum," *Proc. U.S. Nat. Mus.*, Vol. LII (1917), p. 271.

[43] O. P. Hay, p. 542 of ftn. 15 (1929).

they are actually distinct from species named from other areas is by no means certain. *Acanthoessus* should be classified as a placoderm (or aphetohyoidean) rather than as an elasmobranch. *Ca. scitulus* is an edestid fish whose specific designation is uncertain.

The dipnoans have been restudied by Romer and Smith.[44] Since all but one species, *S. cristatus*, were established on the basis of scales and the variation of scales from the nodules is no greater than that in a single living species of lungfish, these writers have referred all such specimens to the first-named species, *S. occidentalis*. They imply that this may not be the true answer to the problem of specific identity, since dipnoan scales are of little or no diagnostic value at the specific level. It appears to be the best solution possible in view of the nature of the material. They refer *S. cristatus* to the genus *Ctenodus* but do not consider the specific relationships of the single tooth plate which is the basis for the species. The species is probably indeterminate, since the preservation of the plate is poor. In recognition of the indeterminate nature of the specimen, it is entered in the faunal list of the present paper as *Ctenodus* sp. Whether this is the same specimen as the undescribed specimen of *Ctenodus* in Eastman's faunal lists or not seems in doubt. In Eastman's first list,[45] *Ctenodus* sp. undesc. is entered, and in the second *S. cristatus* appears in addition. But there is no description of *Ctenodus* by Eastman or by any later writer, and there is good reason to suppose that there is actually only one lungfish tooth from Mazon Creek which has been recorded in the literature.

Only one species of crossopterygian has been described from adequate material, *Co. exiguus* Eastman. *Rhizodopsis?* and *Co. robustus* were described from inadequate fragments. *Co. elegans* was first suggested as being present in a statement by Newberry to the effect that he had received a species of *Coelacanthus* which did not appear to be different from the Linton, Ohio, *Coelacanthus*. Eastman referred several specimens to this species tentatively but was indefinite about their true position. It seems apparent from the available figures that *Co. exiguus* is distinct from the Linton species and that all the other specimens are not far from *Co. exiguus*. More study of the actual specimens is necessary to clarify the situation. For the present, it seems best to refer all specimens of the genus to the one well-defined species, *Co. exiguus*.

Four species of *Elonichthys* have been described. There is a rather large number of species of the small fish known, and restudy of these probably would result in a reduction of the number of species. The differences between the species as described are slight and may be caused by such factors as the degree of maturity and the orientation of specimens designated as holotypes. Until such a study is made, the four species recorded at Mazon Creek should be retained since they are adequately described from determinable specimens.

Platysomus and *Cheirodus* are distinct genera as indicated by the figures by Eastman.[46] That there are two species of *Platysomus* seems doubtful, and a restudy of the materials should be made.

Westoll[47] has restudied certain of the actinopterygian fish and indicated their position in his Family Halpolepidae. He gives a concise summary of the work on

[44] Pp. 702–4 of ftn. 3 (1934).

[45] P. 541 of ftn. 38 (1902).

[46] Pp. 5 of ftn. 40 (1903).

[47] P. 10 of ftn. 37 (1944).

these forms as follows [footnoting altered to conform to practices of *Journal of Geology*].

"Newberry and Worthen[48] described a small fish from this locality as *Palaeoniscus gracilis* Newberry and Worthen. Later Newberry[49] noted the presence of a specimen of *Eurylepis* 'probably not distinct from those found at Linton.' Hay[50] and Eastman[51,52,53] referred *Palaeoniscus gracilis* Newberry and Worthen to the genus *Rhadinichthys*. Later, Eastman[54] described and figured a specimen of *Rh. gracilis* which was later discussed by [L. S.] Berg[55] who referred it to a new genus and species, *Teleopterina improvisa* Berg, the type of a new family. Westoll[56] stated that *Teleopterina* is a synonym for *Pyritocephalus* Fritsch."

The following actinopterygian fish were listed by Westoll in this revision: *Haplolepis* cf. *tuberculata* (Newberry), *H.* cf. *ovoidea* (Newberry), *Pyritocephalus gracilis* (Newberry and Worthen), and *Py. comptus* Westoll.

This revision offers a valid and simple resolution of the difficulties which have plagued this suite of specimens. It is indicative of the sort of revision which is desirable for other actinopterygians and of the sort of solution which might come from such work.

For all cases in which there is serious doubt concerning the validity of species among the fish, the practice, in compiling the faunal list at the end of this section, has been to retain well-described species, pending work which will clarify their status. This almost certainly does not give an accurate representation of the fauna, but it does not, on the other hand, eliminate species which may be valid. The placing of the genera is sufficiently accurate that the all-over aspect of the fauna is well portrayed in the list. For the purposes of the present paper, this accomplishes what is desired—establishment of an adequate basis for general comparisons of the vertebrate localities in the Pennsylvanian of Illinois.

Moodie[57] made a comprehensive report on the amphibians, in which the faunal list given on page 298 of this report was included. Since the publication of his report there have been extensive and fundamental changes in the concepts of classification of the Amphibia. A. S. Romer[58] indicated that not only the four species of amphibians described by Moodie as branchiosaurs but a number of others, including *Amphibamus*, belong in this group. The same writer[59] gave convincing evidence that many branchiosaurs are in reality larval labryinthodonts. This certainly seems to apply to the majority of Mazon Creek specimens, which are clearly im-

[48] "Descriptions of Fossil Vertebrates," *Geol. Surv. Ill.*, Vol. IV (1870), p. 347.

[49] "Paleozoic Fishes of North America," *Monogr. U.S. Geol. Surv. No. 16* (1889), pp. 212, 214–25.

[50] "Bibliography and Catalogue of the Fossil Vertebrata of North America," *Bull. U.S. Geol. Surv.*, Vol. CLXXIX (1902), pp. 1–868.

[51] Pp. 55–99 of ftn. 39 (1902).

[52] Pp. 535–41 of ftn. 38 (1902).

[53] Pp. 163–226 of ftn. 40 (1903).

[54] Ftn. 42 (1917).

[55] "*Teleopterina*, n.g. a highly organized actinopterygian from the Carboniferous of North America," *Compt. Rend.* (Doklady) *Acad. Sci. U.R.S.S.*, Vol. IV (1936), pp. 345–47.

[56] "The Distribution of Certain Specialized Carboniferous Bony Fishes," *Rept., Ann. Meeting Brit. Assoc. Adv. Sci.* (108th yr.; Cambridge, 1938), Sec. C (Geol.), p. 425.

[57] Pp. 3–222 of ftn. 2 (1916).

[58] "The Pennsylvanian Tetrapods of Linton, Ohio," *Bull. Amer. Mus. Nat. Hist.*, Vol. LIX (1930), pp. 77–147.

[59] "Notes on the Branchiosaurs," *Amer. Jour. Sci.*, Vol. CCXXXVII (1939), pp. 748–61.

mature. D. M. S. Watson[60] recognized the great similarity of the more mature branchiosaur skulls, such as that of *Branchiosaurus amblystomus* Credner of Europe, and the labyrinthodonts, and indicated that the branchiosaurs may have come from the embolomeres. Regardless of the interpretation, it seems clear that the branchiosaurs have affinities with the labyrinthodonts and that most of the amphibians from Mazon Creek are actually larval labyrinthodonts. *Micrerpeton*, *Eumicrerpeton*, and *Mazonerpeton* certainly fall in this category. The position of *Erp. mazonensis* is less certain. It consists of a scapula, clavicle, humerus, radius, and possible rib. These bones differ from comparable elements in most branchiosaurs only in the slightly higher degree of ossification of the articular surfaces of the limb bones. Tentative assignment to the branchiosaur assemblage seems to be the best disposition of the genus. *Am. thoracatus*, named from a rather poor specimen, is not closely related to *Am. grandiceps*. Its reference to the genus *Amphibamus* gives a false impression of its affinities, but the specimen is hardly adequate to be the type of a new genus. It is tentatively assigned to the branchiosaurs, and, in order to preserve its identity in the faunal list, it is entered as "*Amphibamus*" *thoracatus*.

Watson re-examined the type of *Am. grandiceps* and a specimen tentatively assigned to that genus by Romer to reach a somewhat different conclusion from that of Romer, who had suggested that the genus belonged to the branchiosaurs. He found that *Am. grandiceps* and the second specimen, which he named *Miobatrachis romeri*, showed marked divergence from the branchiosaurs and that they had progressed in the direction of the primitive anuran, *Protobratrachus*, from the Triassic. These two genera do not belong among the branchiosaurs and and not larval labyrinthodonts. Rather, they are referred to the Family Miobatrachidae, which appears to have given rise to the frogs. Watson suggests retention of the Order Phyllospondyli to include a series of families which he thinks were derived from the labyrinthodont amphibians but which had diverged far enough from the embolomeri to deserve separate ordinal designation. The writer finds himself more in sympathy with the position of Romer, who, in his most recent classification,[61] includes the forms in question either under the Order Embolomeri or, in the case of *Amphibamus* and *Miobatrachis*, under the Order Eoanura in the Superorder Salientia. This treatment appears to express the relationships clearly and to eliminate the use of the term Phyllospondyli, which, if retained, is almost certain to cause confusion beyond any gain in clarity which it may afford.

The conclusion that the Mazon Creek branchiosaurs are larval labyrinthodonts poses a problem of nomenclature, since the mature equivalents are either unknown or not certainly identified with their larval stages at the present time. The practice of referring to the specimens by the names given by Moodie probably will persist until such time as it becomes evident that the names are in synonymy. It is quite possible that the names applied to the larval stages will have priority over the names which have been or will be given to their mature counterparts. For the present, the genera and species considered to be larval labyrinthodonts are entered in the faunal

[60] "The Origin of Frogs," *Trans. Roy. Soc. Edinburgh*, Vol. LX, Part VII (1939–40), pp. 195–231.

[61] *Vertebrate Paleontology* (2d ed.; Chicago: University of Chicago Press, 1945), pp. 590–91.

list under the names applied by Moodie with the understanding that they may prove invalid as relationships are better understood.

In addition to the branchiosaurs and miobatrachids, the fauna contain a poor impression of an amphibian named *Er. branchialis*, an embolomere based on a series of vertebrae, *Spo. spinatum*, and *Ce. ventriarmatum*, which appears to be a microsaur of uncertain family affinities. That a specimen so poor as the type of *Er. branchialis* should have been made the basis for a new genus and species is unfortunate. Reference to the lysorophids was based on very scant evidence, and there can be no real basis for thinking that this group is represented at Mazon Creek by any of the specimens now known. *Erierpeton* is dropped from the faunal list as being indeterminate.

On the basis of the revisions of certain elements of the fauna of Mazon Creek and the suggestions on nomenclature in the less well-studied groups made in the above paragraphs, the revised faunal list from this locality is as follows:

Class Placodermi
- Order Acanthodii
  - Family Acanthodidae
    - *Acanthoessus beecheri* (Eastman)
    - *Ac.* marshi (Eastman)

Class Chondrichthyes
- Subclass Elasmobranchii
  - Order Selachii
    - Suborder Hybodontoidea
      - Family Edestidae
        - *Ca. scitulus* (St. John and Worthen)
  - Order Xenacanthodii
    - Family Xenacanthidae
      - *X. compressus* (Newberry)
      - *X. latus* (Newberry)
      - *X. lucasi* (Newberry)

Class Osteichthyes
- Subclass Actinopterygii
  - Superorder Chondrostei
    - Order Palaeoniscoidea
      - Family Haplolepidae
        - *H.* cf. *tuberculata* (Newberry)
        - *H.* cf. *ovoidea* (Newberry)
        - *Py. gracilis* (Newberry and Worthen)
        - *Py. comptus* Westoll
      - Family Elonichthidae
        - *E. disjunctis* Eastman
        - *E. hypsilepis* Hay
        - *E. peltigerus* Eastman
        - *E. perpennatus* Eastman
      - Family Platysomidae
        - *Pl. circularis* Newberry and Worthen
        - *Pl. lacovianus* Cope
        - *Cheirodus* [*Amphicentrum*] *orbicularis* (Newberry and Worthen)
  - Subclass Choanichthys
    - Order Dipnoi
      - Family Ctenodontidae
        - *Ctenodus* sp.
        - *S. occidentalis* (Newberry and Worthen)
    - Order Coelacanthini
      - *Co. exiguus* Eastman

Class Amphibia
- Subclass Aspidospondyli
  - Superorder Labyrinthdontia
    - Order Embolomeri
      - Family Eogyrinidae
        - *Spo. mazonensis* Moodie
    - Inc. Sed.
      - Branchiosaurs
        - *Erp. mazonensis* Moodie
        - *Eum. parvum* Moodie
        - *M. costatum* Moodie
        - *M. longicaudatum* Moodie
        - *Mi. caudatum* Moodie
        - *"Amphibamus" thoracatus* Moodie
  - Superorder Salientia
    - Order Eoanura
      - Family Miobatrachidae
        - *Mio. romeri* Watson
        - *Am. grandiceps* Cope
  - Subclass Lepospondyli
    - Order Microsauria
      - Inc. Sed.
        - *Ce. ventriarmatum* Moodie

PIASA CREEK LOCALITY

Just below the Piasa limestone at the falls of Piasa Creek, NE. $\frac{1}{4}$, T. 8 N., R. 10 W., in Jersey County, Illinois, occurs a gray shale with phosphatic nodules containing a variety of organic remains. As

yet no vertebrates of taxonomic or morphological significance have been obtained from this deposit, for the known specimens are fragmentary, but the conditions of deposition and the faunal association are of considerable interest.

The shale, which is several feet thick, lies directly beneath the marine Piasa limestone. Above the limestone are additional shales, gray to green in color. These grade upward into red shales. The layer of red shale is about five feet thick and exposed for a distance of about 100 feet. No fossils have been found in the shales which overlie the limestone. The principal interest is in the sequence of beds, which is the same as that at several other places in the state, i.e., gray shale, limestone, gray-green shale, and red shale.

Vertebrates, invertebrates, and plants occur in the shale beneath the Piasa limestone. The vertebrates and invertebrates are in phosphatic nodules, but the plant remains, while encountered in a few nodules, are for the most part represented by fragments of fossil wood ranging from less than an inch to several inches in length and scattered at random throughout the shale. The vertebrates consist of teeth, scales, spines, small complete bones, and larger bone fragments. The specimens represented in some fifty nodules which have been studied are as follows:

Class Chondrichthyes
- *Petrodus*—10 ossicles
- *Lystracanthus*—5 spines
- *Edestus*—1 tooth
- *Orodus*—2 teeth
- A number of indeterminate fish spines, possibly shark

Class Osteichthyes
- Rhipidistians
  - Several proximal fin elements, dorsal fin supports, and scales. Genera indeterminate

The fragmentary condition of the specimens makes specific determination impossible in a number of cases and sufficiently uncertain in all that no reference of the specimens to species has been made. Most abundant are the remains of *Petrodus* and *Lystracanthus*. Here, as elsewhere, the associations are such as to suggest that these may have come from the same type of animal. The rhipidistian bones, although well preserved, do not compare precisely with those described in the few genera in which the fin structure is well known. The bones are not, however, suitable to be used as the basis for a new genus. No identifiable remains of tetrapods have been found. The fragments of large, massive bones may well be tetrapod, but all are so water-worn that their identification is impossible. They appear to have been transported far from their source.

Orbiculoidea cf. *missouriensis* is the only invertebrate which has been found. Specimens in many of the phosphatic nodules are excellently preserved. Plant remains consist entirely of fragments. While water-worn, they show considerable structure. They have not been identified, although this might be possible, but there can be no doubt that they were derived from terrestrial plants and have been carried some distance from their place of growth.

The fossiliferous shales seem to have been laid down during the early stages of transgression of marine waters over the land during the cycle of which the Piasa limestone was deposited. *Orbiculoidea* is not a typical marine brachiopod, nor does it occur in fresh-water deposits. It seems to indicate somewhat unusual conditions of deposition, perhaps brackish water. Associated with it in this shale are *Petrodus*, *Edestus*, and *Lystracanthus*. This association is char-

acteristic of the black, fissile shales of the coal measures but occurs at the Piasa Creek locality in a very different matrix. No conodonts have been found, but it is possible that they might be revealed by an analysis of the shale for microfossils. The rhipidistian bones are well preserved and do not show the water-wear characteristically exhibited by the wood and fragments of larger bones. They do not appear to have undergone any notable transportation. From these indications it would appear that this shale was deposited under brackish-water conditions, perhaps in an estuary, and that the sharks and rhipidistians were in existence in the waters at the site of the deposit. They may give evidence of the initial migration of the choanichthys into salt waters, a step fully accomplished by the coelacanths in the Permian. The shale was followed by a limestone deposited under strictly marine conditions. No vertebrates, plants, or *Orbiculoidea* occur in the limestone.

MARION COUNTY LOCALITY

A specimen of *Xenacanthus* was obtained from a plant-bearing gray shale along the course of a creek in the SW. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 30, T. 4 N., R. 4 E. in Marion County, Illinois, by Prof. J. Marvin Weller. This specimen (W. M. 1904) was turned over to the writer for study. It consists of twenty teeth and well-preserved parts of the calcified chondrocranium and jaws. The remains all seem to be parts of one individual. The teeth resemble those of *X. latus* (Newberry) closely, although the central denticle is rather fully developed on the smaller teeth. The shark appears to have been an isolated specimen. This type of occurrence in nonmarine beds, as the gray shale appears to be, may be encountered occasionally, but it is apparently futile to explore such shales in an effort to find vertebrates, since their occurrence is very uncommon. Several similar occurrences, commonly of merely a few teeth, have been reported from a number of areas in the state.

SUMMARY AND CONCLUSIONS

Vertebrates occur in various types of beds in the Pennsylvanian of Illinois, in red-and-gray nonmarine shales, in channel sandstones, in ironstone nodules in the coal measures, in phosphatic nodules in gray shales deposited in brackish waters, in nonmarine, plant-bearing gray shales, in black fissile shales, in cannel coal, and in typical marine beds. In no instances are the specimens preserved in a condition which makes their study entirely satisfactory. The closest approach to good preservation is in the ironstone nodules and the cannel coal. The latter seem to offer the possibility of yielding excellent specimens but as yet only one has been recovered.

A study of the faunas from these different environments gives a moderately adequate knowledge of the types of fish which were developed during the Pennsylvanian. The fresh-water sharks show little difference from those of the lower Permian and do not differ greatly from their Devonian predecessors. There is evidence that the cladoselachian type of shark, represented by *Ctenacanthus*, lived in fresh water during the Pennsylvanian. Lungfish are similar to those of the lower Permian, *Sagenodus* being the principal genus. In addition, there is an ancestral *Ceratodus*-like genus, *Proceratodus*, which is unknown in the Permian. Remains of other choanichthys are rare. Best known are the small coelacanths from Mazon Creek. The only other occurrence is in the supposed brackish-water deposits of Piasa Creek from which rhipidistians

have been obtained. There is a suggestion that the crossopterygian type was undergoing transition from fresh to marine waters. The known actinopterygians are all palaeoniscids. These were fresh-water fish and are not decidedly different from their Permian descendants.

Knowledge of the tetrapods remains far from satisfactory. A rather large number of genera representing several families has been recorded, but specimens tend to be disarticulated and broken so that it is difficult to determine much concerning their morphology. The best-known specimens come from the ironstone nodules of Mazon Creek, and many of these appear to be larval labyrinthodonts. They suggest that there was a moderately diversified fauna of medium-sized amphibians, perhaps not unlike those recorded from the Dunkard, Abo, Wichita, and Clear Fork beds. Few remains of mature individuals have been found. There are fragmentary remains of embolomeres in the nodules and in the shale at Oakwood. The rhachitomi are represented only by a few scraps from the Falmouth locality. Among the most significant specimens are *Amphibamus* and *Miobatrachus*, small but mature ancestral anurans from Mazon Creek. Lepospondyls are known from vertebrae of *Lysorophus* and *Diplocaulus* from Oakwood and from fragments assigned to the Gymnarthridae from Falmouth. A microsaur of uncertain affinities has been found at Mazon Creek. Reptiles are represented only by the primitive pelycosaur, *Clepsydrops*. These tetrapods lead to the conclusion that there actually was a well-developed terrestrial fauna, but so little is known of it that we can only get the barest insight into its true relationship to descendant faunas.

There are prospects that future work in the state will reveal other localities which will enlarge the knowledge of the Pennsylvanian vertebrates of Illinois. Most hopeful are various sandstone channel deposits which have not been thoroughly investigated for vertebrate remains. It is the writer's hope to visit a number of known channels in the near future. Cannel coals also offer possibilities, but their investigation must be concurrent with mining operations, which makes present study impossible. Additional deposits of the type found at Oakwood would seem to offer little possibility of success, although it is not impossible that new localities may turn up in the course of stratigraphic work on similar beds. It is to be anticipated that new specimens of fish and amphibians will be obtained from ironstone nodules as paleobotanical work continues in the Mazon Creek area.

SUBMARINE PHOTOGRAPHY OFF THE CALIFORNIA COAST[1]

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University of California Division of War Research

ABSTRACT

Bottom photography with the Ewing submarine camera was employed during the war to determine the bottom character of various areas off southern California and Mexico (Fig. 1). The photographs provide information on the appearance of the sea floor on the continental shelf, on the submerged banks, and on the walls of submarine canyons. These pictures indicate the rocky nature of extensive portions of the sea bottom. An abundance of rounded boulders and cobbles is also shown, but growth of delicate organisms on these rocks implies that rolling is now slight. Ripple marks are present on sand in areas particularly exposed to waves and currents. Finally, the smoothness of most sediment surfaces is impressive, although the surfaces of muddy sediments usually have small depressions.

INTRODUCTION

One of several large contributions by Maurice Ewing to submarine geology has been his development of a practical method of taking photographs of the sea bottom. In the course of work at the University of California Division of War Research at the United States Navy Electronics Laboratory, San Diego, we had the opportunity to make use of this new device. The results of this work are not the product of a purely scientific program, but they do show what can be expected from future work having a different emphasis.

The equipment used in submarine photography is illustrated in Figure 2. An automatic re-wind camera is housed in a brass case having a glass porthole. The case is mounted on a pole, and a reflector and flash bulb are attached beneath. The camera case and flash bulb are connected by an electrical circuit, which can be tripped by a weight suspended below the pole. In operation, the instrument is attached to a cable on a suitable winch and, after being cocked, is lowered to the sea floor. Spinning because of cable twist is retarded by a small vertical sail on the camera pole and by a swivel between the pole and cable. When the weight strikes bottom a spring closes the circuit and the camera and flash bulb operate synchronously. As soon as the device has touched bottom the outgoing cable is stopped and hoisting begun. When the camera is again at the surface it is cocked and a fresh bulb inserted. More elaborate devices were tried, but without success. Even this method required some assistance from electricians and photographers. Water pressure, rough bottoms, and the chemical effect of sea water all conspire against the continuous success of the operations.

Most of the pictures were taken with black-and-white film, but a few rolls of indoor Kodachrome were used. For naval research purposes black-and-white was more practical, since it allowed immediate developing of the films to show whether results were being obtained. For future work, color photography will undoubtedly prove superior, since the colors bring out features which are not ap-

[1] This work represents one of the results of research carried out by the University of California Division of War Research under contracts with the Office of Scientific Research and Development, Section 6.1; with the National Defense Research Committee; and with the Bureau of Ships, Navy Department.

[2] Scripps Institution of Oceanography.

[3] University of Southern California.

parent in black-and-white films. Some research will be necessary, however, before one can obtain approximately true colors of objects as they would appear to a diver.

Photographs were taken to depths as great as 140 fathoms. In the early operations the camera was only slightly inclined from the pole, so that the reflector and weight show in the picture, as in

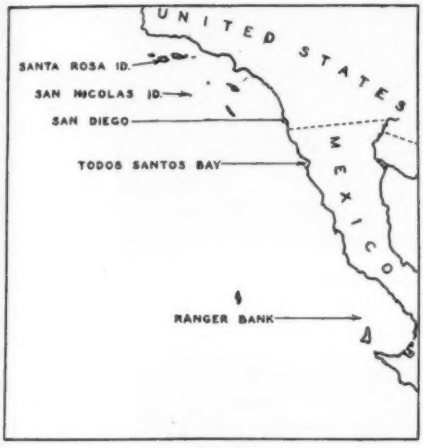

FIG. 1.—Map showing principal areas from which bottom photographs were obtained.

Figure 4. Later the case was rotated so that the photographic axis was inclined about thirty degrees from the vertical. On the average, the pictures covered about fifteen square feet, depending, of course, on the height of the camera above the bottom and on the inclination. With very clear water a much larger area can be covered by shooting from well above the bottom.

SAND AND MUD BOTTOMS

Many of the photographs are completely lacking in features of interest, particularly where detail was obscured by turbidity of the water. Some photographs of sand or mud bottoms show almost flat surfaces. The mud content of the sediment is sometimes indicated by the incipient mud cloud which is raised by the weight's hitting bottom. If the photograph were not taken almost immediate-

FIG. 2.—Showing the general operation of the Ewing submarine camera.

ly after contact, this cloud might obscure bottom. The mud surfaces usually show small depressions (Fig. 3), presumably due to burrowing organisms. The most striking feature of the sand surfaces is the number of photographs which are free from ripple marks (Fig. 4). This is true even in depths as slight as 15 fathoms. However, these areas may not always be free from ripples, since most of the pictures were taken during times of

FIG. 3.—Mud, 110 fathoms, Todos Santos Bay (Lat. 31°48.2′, Long. 116°46.6′). Showing small depressions typical of muddy surfaces.

FIG. 4.—Coarse sand and shells, 14¾ fathoms, San Diego area (Lat. 32°38.06′, Long. 117°14.30′)

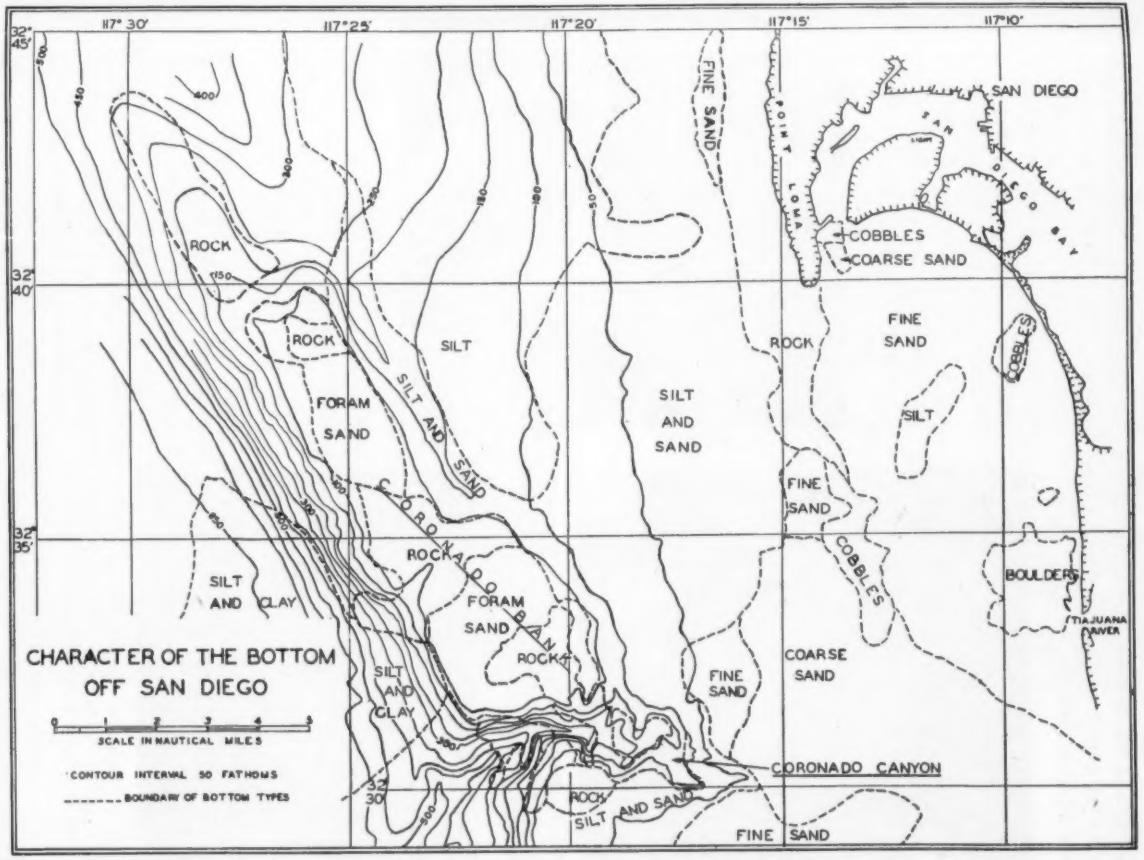

FIG. 5.—Bottom sediment chart of San Diego area

relatively smooth seas. Attempts to photograph the bottom after a rain-and-wind storm were not very successful because of high turbidity.

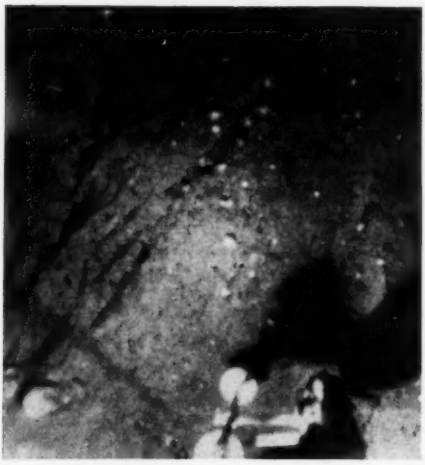

FIG. 6.—Rock, 62 fathoms, Coronado Bank (Lat. 32°32.9′, Long. 117°20.2′). Lines suggest eroded edges of tilted bedding planes.

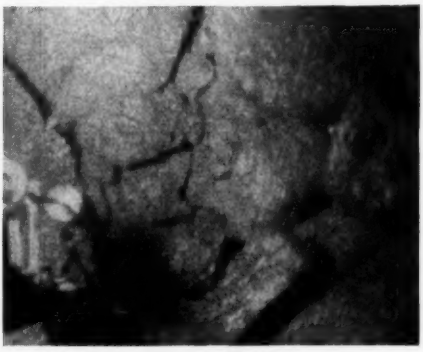

FIG. 7.—Rock, 60 fathoms, Coronado Bank (Lat. 32°33.0′, Long. 117°20.1′). Note angularity of rocks and abundance of attached marine life.

BANKS AND SHELVES

In previous work dredgings were made rather extensively on the banks and seamounts off the southern California coast.[4]

[4] K. O. Emery and F. P. Shepard, "Lithology of the Sea Floor off Southern California," *Bull. Geol. Soc. Am.*, Vol. 56 (1945), pp. 431–78.

Many dredge hauls recovered both angular fragments of ledge rock and rounded cobbles or pebbles. In some areas the rocks were completely buried in sediments and in others they were largely exposed as shown by the presence of incrusting organisms. Photography gives one a better idea of actual conditions on these banks than dredging. Numerous photographs were made on Coronado

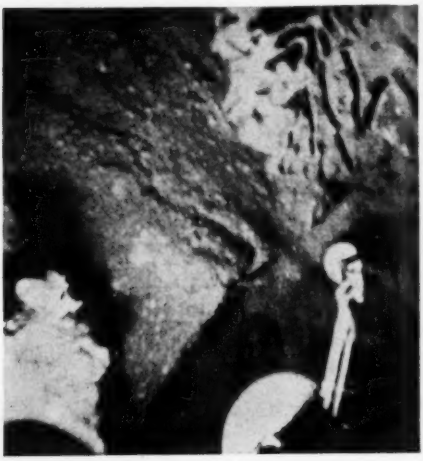

FIG. 8.—Rock, 57 fathoms, Coronado Bank (Lat. 32°32.4′, Long. 117°20.4′). The photograph indicates several types of rock at various levels. Note the wrinkled mass in the upper right and the overhanging rock with a cup coral in the lower left.

Bank, which lies about ten miles southwest of San Diego (Fig. 5). Here surfaces varied from bare rock through cobbles to somewhat muddy foraminiferal sands. The rock surfaces are shown in Figures 6–10. Bedding planes in Figure 6 may indicate a tilted series of rocks. Figure 7 shows large jointed blocks of rock covered with organisms, notably brachiopods and red calcareous algae (the latter are pink in the Kodachrome transparencies). A brachiopod and a crab can be seen just above the camera trip weight. Figure 8 is perhaps the most amazing of

FIG. 9.—Rock and foraminiferal sand, 86 fathoms, Coronado Bank (Lat. 32°33.9′, Long. 117°23.1′). The rock resembles masses of phosphorite, such as have been dredged in abundance from this area. Many shells are present.

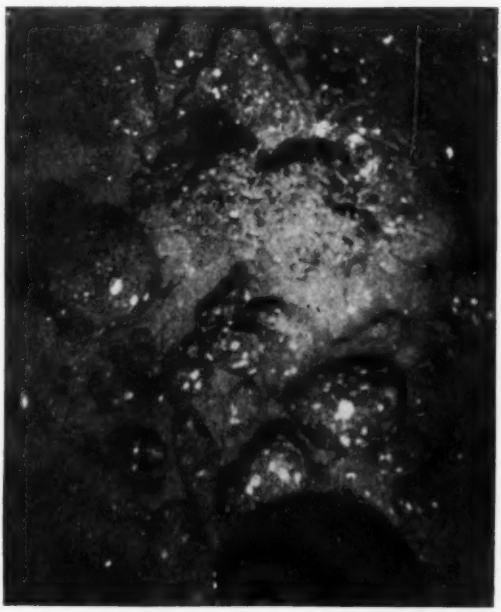

FIG. 10.—Cobbles, 67 fathoms, Coronado Bank (Lat. 32°32.5′, Long. 117°19.9′). Note the encrusting organisms on these cobbles.

FIG. 11.—Rock and boulders, 82 fathoms, Ranger Bank (Lat. 28°31.6′, Long. 115°30.3′). A small fish (*Sebastodes*) and a sea fan (*Gorgonia*) are visible upper right.

FIG. 12.—Foraminiferal sand, 70 fathoms, Ranger Bank (Lat. 28°28.2′, Long. 115°31.5′). Note the faint ripples and the starfish.

the photographs. So far as one can tell, the surface is washed clean of sand. There appear to be several levels of rock. The lowest may be shale and the next resembles a soft limestone full of shell fragments which was dredged from this area. The wrinkled mass in the upper right may be contorted shale or perhaps some unidentified organism. Figure 8 also shows a cup coral in the lower left attached to a projecting rock mass. More photographs in this area will be taken as soon as possible.

Surfaces with cobbles and boulders are also common. Some of the mammillary surfaces, as in Figure 9, are probably phosphorite, which appears to be forming on the banks.[5] Other rocks, as in Figure 10, are rounded, presumably by rolling.

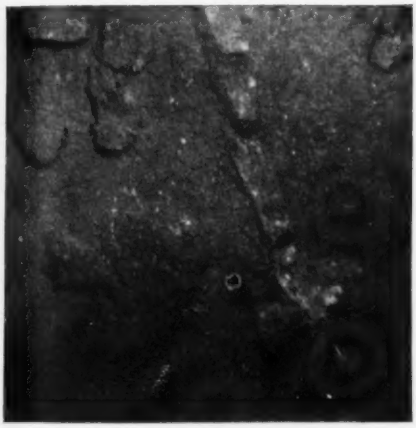

FIG. 13.—Rock and foraminiferal sand, 62 fathoms, San Nicolas Island area (Lat. 33°23.1′, Long. 119°40.9′). Tilted ledge rock and crinoids.

The incrusted surface indicates that rolling does not now occur.

Ranger Bank, off Mexico (Fig. 1), provided several good photographs because of the clearness of the water. This bank is also partly rock and partly covered with foraminiferal sand. The pictures of the rock show a group of large angular blocks and boulders (Fig. 11). Fish can be seen in each picture. The rocks are

FIG. 14.—Rock, 62 fathoms, San Nicolas Island area (Lat. 33°25.1′, Long. 119°46.4′). Large pieces of ledge rock.

heavily incrusted, suggesting that here, also, there is no rolling at the present time. This was the more significant since these photographs were taken toward the end of the storm season. However, there are indications of turbulent bottom conditions, since the sand pictures show rather faint ripples (Fig. 12).

Another rocky area was found on the submerged ridge connecting Santa Rosa and San Nicholas islands (Fig. 1). Shelves less than 100 fathoms deep extend out from both islands and are separated by a saddle about 220 fathoms deep. These insular shelves correspond to banks in that they have deep water on either side. The notations on charts of this area led to the false impression that the bottom was predominantly sand-covered. Photo-

[5] R. S. Dietz, K. O. Emery, and F. P. Shepard, "Phosphorite Deposits on the Sea Floor off Southern California," *Bull. Geol. Soc. Am.*, Vol. 53(1942), pp. 815-43.

FIG. 15.—Boulders and cobbles, 85 fathoms, Santa Rosa Island area (Lat. 33°39.1′, Long. 119°57.4′). Feather crinoids (*Comatulids*) are growing on the larger rocks.

FIG. 16.—Foraminiferal sand, 55 fathoms, San Nicolas Island area (Lat. 33°21.4′, Long. 119°42.7′). Alignment of crinoids (*Comatulids*) may indicate slightly buried, tilted layers of rock.

FIG. 17.—Rock and foraminiferal sand, 73 fathoms, San Nicolas Island area (Lat. 33°25.9′, Long. 119° 49.4′). The crabs (*Lopholithoides foraminatus*) appear to be all facing toward the fish in the lower center.

graphs reveal that this sand is mostly discontinuous and that rocks are predominant. It could, of course, be possible that samplers would recover only sand in such places. Figures 13 and 14 appear to show ledge rock. Apparently these rocks are consolidated sediments which have been tilted and truncated. In Figure 15 the rocks are rounded, indicating that rolling has taken place. Again, the rocks are much incrusted and feather crinoids are attached. Figure 16 shows a group of the crinoids with an apparent alignment, possibly due to the presence of a rock layer underlying a thin sand cover and affording a foothold for the crinoids. These photographs represent the first evidence of the actual habitat of these

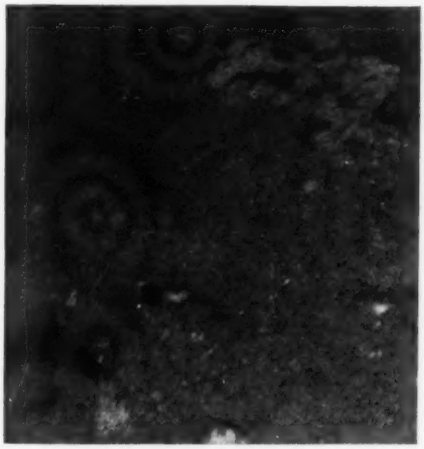

FIG. 18.—Rock and foraminiferal sand, 115 fathoms, Santa Rosa Island area (Lat. 33°47.1′, Long. 120°02.4′). Several types of sponges are shown.

deep-living organisms. In another place we found a number of crabs all pointed in the same direction and facing a fish (Fig. 17). In Figure 18 two or more types of sponges are to be seen on a rock bottom.

A few pictures of the San Nicolas–Santa Rosa Island area indicate the nature of the break in slope at the edge of the shelves. These rocks appear to preclude the possibility of extension of the insular shelf by wave-building. Figure 19 shows that the upper part of the slope

FIG. 19.—Rock, 105 fathoms, San Nicolas Island area (Lat. 33°28.2′, Long. 119°51.8′). Heavily encrusted rocks on the scarp bordering the insular shelf.

is very irregular. It is interesting that the incrustations should be pronounced at a place where the depth is over 100 fathoms. Color would be a great help in deciphering photographs of this sort. The presence of the weight and rope in these pictures suggests that the weight hit on a slope and slid a short distance down this slope before it stopped and released the spring. During the sliding the camera was moved in such a way as to bring the weight into the field of view.

Off Todos Santos Bay, lower California, there is an area of numerous small rocky banks which rise above the general level. A section made by the recording Fathometer illustrates this situation (Fig. 20). The pictures taken along the line of this section show rock bottoms on

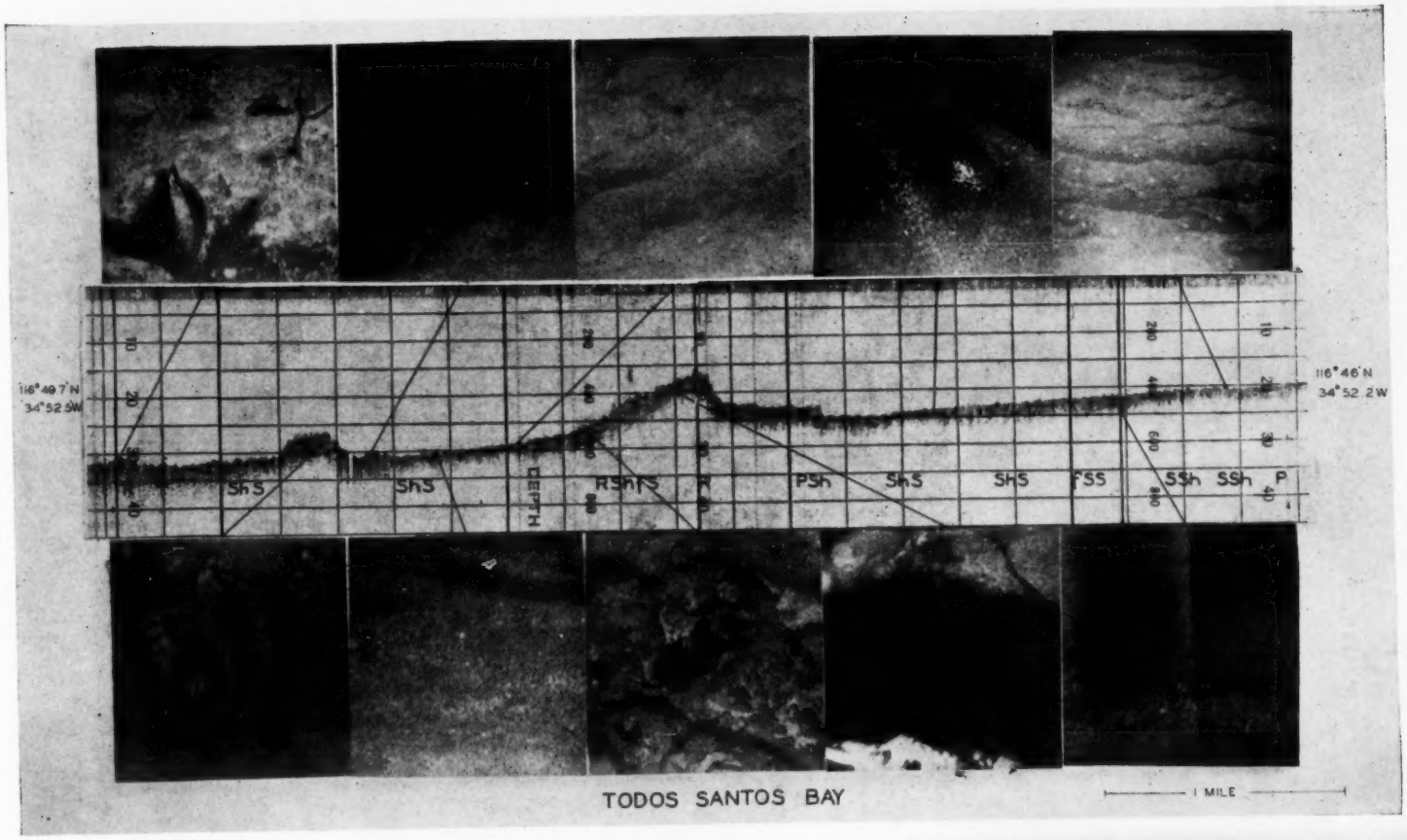

FIG. 20.—Todos Santos Bay. Relationship of bottom materials and topography as shown by a Fathometer trace. Note that the rocks are found on the high areas and the ripple-marked sands in the intervening lows.

FIG. 20.—Todos Santos Bay. Relationship of bottom materials and topography as shown by a Fathometer trace. Note that the rocks are found on the high areas and the ripple-marked sands in the intervening lows.

FIG. 21.—Sand, 23 fathoms, Todos Santos Bay (Lat. 31°52.4′, Long. 116°46.3′). Ripple marks having a wave length of about one-half foot.

FIG. 22.—Sand, 26 fathoms, Todos Santos Bay (Lat. 32°52.56′, Long. 116°46.7′). Giant ripples with wave lengths of three feet or more. Note the shells in the trough.

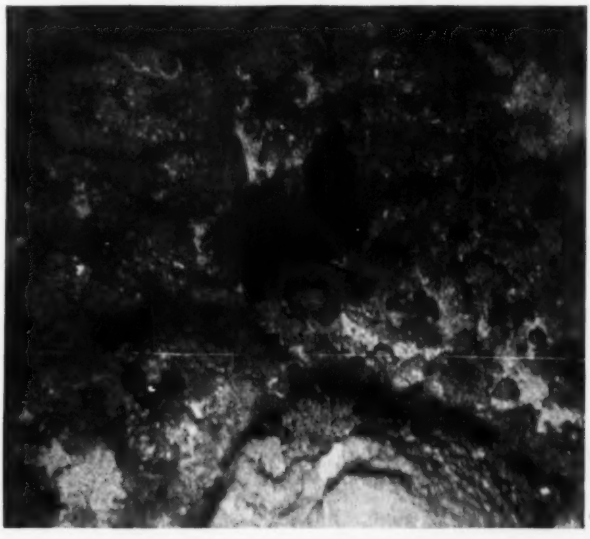

FIG. 23.—Rock and boulders, 22 fathoms, Todos Santos Bay (Lat. 31°52.6′, Long. 116°47.8′). Some type of algae is shown in the center of the picture.

the banks alternating with sand bottoms in the lower, flat areas between the banks. The sand zones are interesting, in that they all show ripples. Photographs of the ripples (Figs. 21 and 22) reveal that there are two types: one is the ordinary shallow-water ripple with about a six-inch wave length, and the other a giant ripple with a span of several feet between crests, so that only one ripple occupies the entire picture. The giant ripples may indicate strong tidal currents, since ripples elsewhere are known to exist only in areas of strong currents. It is notable that photographs of the shallower sand and silty sand areas near-

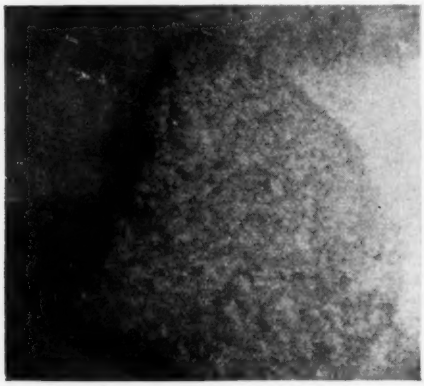

FIG. 24.—Boulder, 38 fathoms, Todos Santos Bay (Lat. 31°53.6′, Long. 116°50′). This rock is three or four feet in diameter.

FIG. 25.—Boulders, 53 fathoms, Todos Santos Bay (Lat. 31°53.0′, Long. 116°50.4′). These rounded boulders are found near the edge of the shelf.

FIG. 26.—Rock, 29 fathoms, Todos Santos Bay (Lat. 31°52.5′, Long. 116°49.8′). The kelp (*Isenia*, related to *I. arborea*) probably drifted from place of growth.

er shore lack ripples. The rocky hills do not show definite outcrops, but no great doubt can be expressed that the boulder masses which are shown in Figures 23–25 represent somewhat weathered masses of ledge rock. Figures 24 and 25 show transported boulders, although their location on a hill precludes any possibility of much transportation under present conditions. Figure 26 shows a complete kelp plant, identified by Dr. E. Yale Dawson as *Isenia*, probably a new species. This picture was taken at 29 fathoms, but the kelp had probably floated from its place of growth.

FIG. 27.—Cobbles and boulders, 22 fathoms, San Diego area (Lat. 32°34.5′, Long. 117°13.2′). The growth on these rounded rocks at shallow depth is impressive.

FIG. 28.—Rock and sand, 16 fathoms, San Diego area (Lat. 32°37.2′, Long. 117°14.7′). Low-lying pink algae growing on the rocks.

RIVER COBBLES

In contrast to the boulders in the ledge-rock areas, an area south of San Diego (Fig. 5) appears to represent a true boulder-cobble bed, presumably deposited by the Tijuana River (off which it lies) at a time of greater coastal emergence. Directly off the river mouth there is a fine-sand deposit. One-half mile out, in about seven fathoms, is a boulder bed extending out another one-and-one-half miles. Beyond that is a fine-sand patch extending two miles out to a depth of about 20 fathoms. This is succeeded by a cobble-and-sand area having some interspersed boulders. This last area extends about one mile out to 24 fathoms' depth and has been traced laterally about four miles. Figure 27 was taken on this outer cobble bed. Despite much dredging, no bedrock has been found along this stretch of bottom. All the rocks recovered are rounded and bear a close resemblance to the alluvial cobbles found in many places along the coast. Growth on the cobbles indicates the absence of much rolling. However, the pictures were taken in the fall before the winter storms and after the summer period when rapid growth could be expected.

FIG. 29.—Rock, 105 fathoms, Coronado Canyon (Lat. 32°31.5′, Long. 117°20.8′). Platy layers of rock protrude on the submarine canyon wall.

North of the cobble area ledge rock is found. Photographs of the bottom in this area (Fig. 28) show small algal masses growing on the rock surface. The depth is 16 fathoms, in this case.

SUBMARINE CANYONS

The submarine canyons are a particularly fruitful field for investigation by submarine photography, and it is unfortu-

nate that the work did not allow more opportunities to photograph them. However, a few pictures were obtained of each wall of Coronado Canyon, which heads eight miles from shore off the Tijuana River (Fig. 5). It was no surprise to find that the majority of the photographs revealed the presence of rock (Figs. 29 and 30). Figure 29 shows definite outcrops, with platy slabs which project slightly in some places. Figure 30 shows a possible ravine. Those who like to think of submarine canyons as being formed by feeble mud currents flowing down muddy oceanic embankments would do well to consider the significance of these rocky walls.

ACKNOWLEDGMENTS.—Help was received from many members of the laboratory in this work. Particular mention should be made of the assistance of Mr. Albin A. Putzker and Mrs. Anne King.

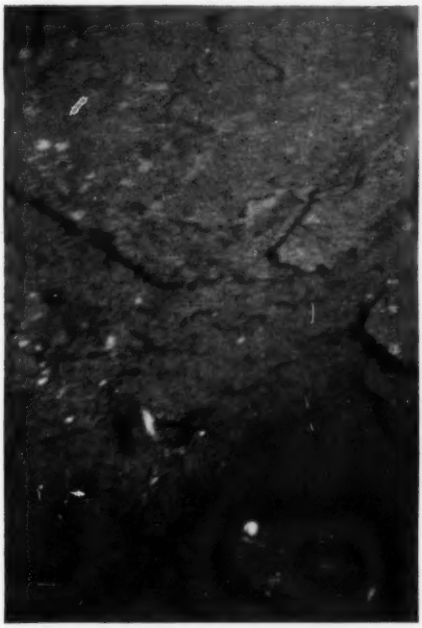

FIG. 30.—Rock, 90 fathoms, Coronado Canyon (Lat. 32°31.8′, Long. 117°21.3′). Possible small ravine cut in the rocky slope shown in the lower right corner.

THE GEOLOGY OF CATARACT FALLS, OWEN COUNTY, INDIANA

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ABSTRACT

At the double falls of Mill Creek near Cataract, Owen County, Indiana, more than 100 feet of Mississippian strata, ranging from the Lower Chester down through the entire Ste Genevieve and into the St. Louis below, are unusually well exhibited. The top of the Ste Genevieve limestone is marked by a thin limestone breccia and followed by a thin representative of the Aux Vases sandstone of the Lower Chester. In the middle of the Ste Genevieve is a fine-grained, calcareous sandstone, 23 feet in thickness, forming the face of the upper falls. This sandstone, described for the first time in Indiana, is correlated with the Rosiclare sandstone of southern Illinois and western Kentucky. Both the Aux Vases and the Rosiclare sandstones are present throughout the outcrop area of the Chester and Ste Genevieve formations in southwestern Indiana, though their recognition has long been delayed.

Near the village of Cataract, in northern Owen County of middle southwestern Indiana, Mill Creek, a sluggish stream draining approximately 250 square miles of glacial drift country, suddenly makes two plunges totaling more than 80 feet in two falls and the cascades which precede them. The upper falls has a sheer plunge of 20 feet and is preceded by noisy cascades, totaling 23 feet, over the rocky stream bed. The lower falls, about ½ mile downstream, has a fall of 17½ feet, preceded by rapids and cascades over 21 feet of exposed rock, all below the rock exposed in the upper falls. The double falls of Mill Creek are without equal in size elsewhere in Indiana, though the locality is not widely known and is only rather sparingly visited for its scenic interest.

The double falls near Cataract appear to have resulted from the presence of two preglacial rock ridges buried beneath Illinoian lacustrine deposits and encountered by the post-Illinoian Mill Creek superposed on them. During the retreating stages of the Illinoian glacial ice some barrier northwest of the Cataract locality permitted a large lake to develop, and the deposits accumulating in it built up an extensive lacustrine plain, known as the Quincy lacustrine plain, at an altitude of approximately 755 feet. Mill Creek, with its drainage leading generally westward, has cut a shallow valley into the lacustrine plain above Cataract Falls and a deep valley in a preglacial course below the falls. The buried bedrock ridges encountered near Cataract have prevented deep cutting into the lacustrine deposits in the upper section of the stream course, and the expansive lacustrine plain is nearly intact over an area exceeding 40 square miles east and northeast of the falls. Presumably, a buried, preglacial drainage course lies at some depth beneath the old lake plain. The two buried bedrock ridges near Cataract were apparently separated by a small preglacial valley leading northeastward between them to the major preglacial course, which the present stream has entered and re-excavated below the lower falls. The buried bedrock ridge encountered at the site of the upper falls is the main barrier of the present stream, having an altitude of about 740 feet. It has been cut deeply into on its lower side, about 20 feet below its former crest, by Mill Creek, revealing an excellent stratigraphic section at the falls site.

More than 100 feet of rock strata are well exposed in the two falls, the cascades, and the adjacent rock walls of the stream. Only casual references to these exposed strata occur in the literature

bearing on the region. They are referred to merely as belonging to the "St. Louis" or to the "Mitchell" limestones of Lower Carboniferous or Mississippian age. It does not appear that any detailed study previous to the present one has ever been made of the formations so well exposed in and about the falls. This is obvious when it is observed that the entire upper falls is over a massive sandstone bed and not over limestone beds, as the references imply.

A careful study of the rock formations exposed in the two Cataract falls, the cascades, and the immediate bluffs reveals the presence of two Chester formations, the entire Ste Genevieve, and some 10 feet or more of the upper part of the St. Louis limestone. All these strata are graphically presented in Figure 1 in proper stratigraphic arrangement, along with the measured thicknesses and the descriptions of the individual beds making up each of the stratigraphic divisions. The central interest is the massive calcareous sandstone, at least 23 feet thick, which composes the rock of the upper falls. This sandstone is in the middle of the Ste Genevieve limestone formation. The top of the sandstone is back of the lip of the falls, and the bottom is below the water level of the plunge pool and is not exposed. Careful examination indicates that it extends at least 2 feet and possibly as much as 3 feet below pool level. No such sandstone in the Ste Genevieve in Indiana has previously been described. It is unlikely that it has not been recognized as a sandstone in the conspicuous falls, though its stony whiteness gives it the appearance of limestone except on close inspection. The writer has known of its presence at the falls for more than twenty years, though no close study of it had been made until recently (see Figure 2).

As shown in Figure 1, the massive sandstone of the upper falls is in the middle of the Ste Genevieve. Above it are 22 feet of limestone strata, dominantly oölitic, belonging to the Ste Genevieve. These strata are well exhibited in the cascades above the falls. The top of the Ste Genevieve is well marked slightly above the level of the dam at the head of the cascades, 150 feet back from the falls, where the Aux Vases sandstone, the basal formation of the Chester series, rests upon it. The lower part of the Ste Genevieve is exposed in and near the lower falls, as shown in Figure 1. Here the lower limestone of the Ste Genevieve measures 30½ feet in thickness. The whole of the Ste Genevieve, as exposed and measured in and near the two Cataract falls, is 75½ feet in thickness, or possibly as much as 1 foot more. The sandstone in the middle composes nearly one-third of the thickness of the entire formation in the Cataract Falls locality. This sandstone is in the stratigraphic position of the Rosiclare sandstone of southern Illinois, and it is herewith correlated with it directly, though previously I have hesitated to make such a correlation because of its remoteness and have referred to it as the "Cataract Falls" sandstone. The 22 feet of limestone above it and below the widely distributed, but thin, Aux Vases sandstone (not previously described in southern Indiana) may be correlated with the Levias limestone, a name given to the limestone beds of the Ste Genevieve above the Rosiclare sandstone and below the Chester beds in western Kentucky by A. H. Sutton and J. M. Weller in 1932.[1] The limestone beds below the Rosiclare sandstone and above the St. Louis limestone have been designated as "Fredonia," and the beds of the Cataract

[1] "Lower Chester Correlation in Western Kentucky and Illinois," *Jour. Geol.*, Vol. XL (1932), p. 439.

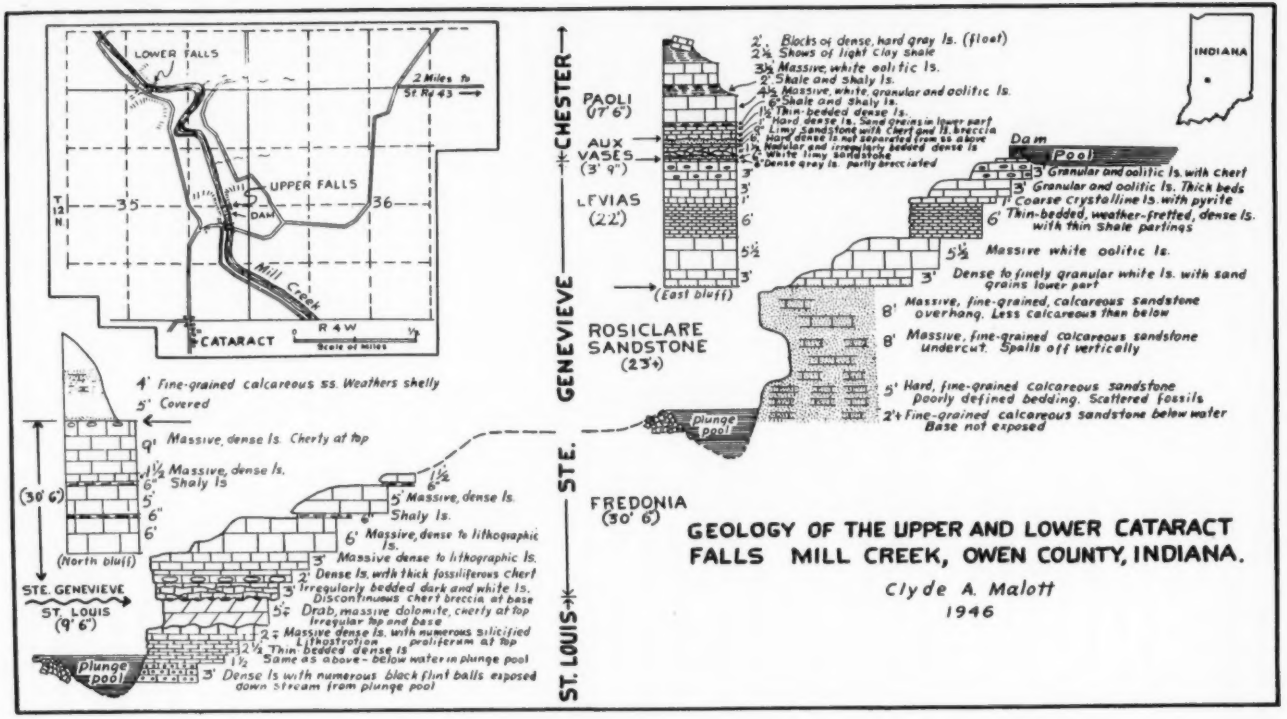
LOWER FALLS
2 Miles to St Rd 43
UPPER FALLS
DAM
Mill Creek
T 12 N
35
36
CATARACT
R 4 W
Scale of Miles
INDIANA
Dam
Pool
CHESTER
GENEVIEVE
ST. LOUIS
STE.
PAOLI (17' 6")
AUX VASES (3' 9")
LEVIAS (22')
ROSICLARE SANDSTONE (23+)
FREDONIA (30' 6")
(East bluff)
(North bluff)
(30' 6")
STE. GENEVIEVE
ST. LOUIS (9' 6")
Plunge pool
Plunge pool
2' Blocks of dense, hard gray ls. (float)
2½ Shows of light clay shale
3½ Massive, white oolitic ls.
2' Shale and shaly ls.
4½ Massive, white, granular and oolitic ls.
6" Shale and shaly ls.
1½ Thin-bedded dense ls.
1' Hard dense ls. Sand grains in lower part
5" Limy sandstone with chert and ls. breccia
6" Hard dense ls not separated from ss above
1½ Nodular and irregularly bedded dense ls
6" White limy sandstone
3' Dense gray ls. partly brecciated
3' Granular and oolitic ls. with chert
3' Granular and oolitic ls. Thick beds
1' Coarse crystalline ls. with pyrite
6' Thin-bedded, weather-fretted, dense ls. with thin shale partings
5½ Massive white oolitic ls.
3' Dense to finely granular white ls. with sand grains lower part
8' Massive, fine-grained, calcareous sandstone overhang. Less calcareous than below
8' Massive, fine-grained calcareous sandstone undercut. Spalls off vertically
5' Hard, fine-grained calcareous sandstone poorly defined bedding. Scattered fossils
2'+ Fine-grained calcareous sandstone below water Base not exposed
4' Fine-grained calcareous ss. Weathers shelly
5' Covered
9' Massive, dense ls. Cherty at top
1½ Massive, dense ls.
6" Shaly ls
6'
5'
6"
6'
5' Massive, dense ls.
6" Shaly ls.
6' Massive, dense to lithographic ls.
3' Massive dense to lithographic ls.
2' Dense ls. with thick fossiliferous chert
3' Irregularly bedded dark and white ls. Discontinuous chert breccia at base
5½ Drab, massive dolomite, cherty at top Irregular top and base
2½ Massive dense ls. with numerous silicified Lithostrotion proliferum at top
2¼ Thin bedded dense ls
1½ Same as above - below water in plunge pool
3' Dense ls with numerous black flint balls exposed down stream from plunge pool
GEOLOGY OF THE UPPER AND LOWER CATARACT FALLS MILL CREEK, OWEN COUNTY, INDIANA.
Clyde A. Malott
1946

FIG. 1

Falls section occupying the same stratigraphic position may be called the "Fredonia limestone." These correlations are made on the stratigraphic chart (Figure 1).

The thin basal Chester sandstone formation, here correlated with the Aux Vases, at and slightly above the level of the dam back from the upper falls at Cataract is only 3 feet, 9 inches thick. It consists of two thin, limy sandstones, varying from a few inches to possibly 1 foot each in thickness, separated by irregular limestone beds and by more or less nodular limestone about 18 inches in thickness. The thin sandstone beds locally contain fragments of rounded and subangular dark limestone, which give the sandstone the appearance of a conglomerate in places. The lower thin sandstone locally rests on a brecciated limestone below it. This bed of brecciated limestone may be recognized at the top of the Ste Genevieve limestone in nearly every section where its stratigraphic position occurs throughout the outcrop belt in southern Indiana, and it is frequently present without the occurrence of any sandstone between it and the Chester limestone above. The upper thin sandstone layer composes the rock platform at the top of the cliff on the west side of Mill Creek a few feet above the level of the dam and for about 200 feet along the bluff above the cascades and the falls. Elsewhere through the outcrop belt it is not common to have two layers of sandstone separated by limestone marking the Aux Vases horizon.

FIG. 2.—View of the Rosiclare sandstone composing the middle part of the Ste Genevieve formation at the upper falls at Cataract, Owen County, Indiana.

A short distance downstream from the upper falls the rather massive Paoli limestone appears above the Aux Vases sandstone formation and forms the brow of the bluff. On the opposite or east side of the falls and cascades the Aux Vases sandstone formation is closer to the level of the dam and not so well exposed. The Paoli limestone above it is broken by two thin beds of easily weathered limy shale and a bed of gray shale near the top,

which show better on the east side than on the steep and rather inaccessible cliff of the west side, a short distance downstream from the falls. The thickness of the Paoli measures approximately 17 feet, though the top is very poorly exposed. The top 2 feet occur as blocks of limestone on the poorly exposed light shale, which is about 30 inches thick. This shale could possibly be interpreted as a thin representative of the Mooretown (sandstone) formation which succeeds the Paoli, but at other localities a similar shale bed has been observed near the top of the Paoli with a normal full thickness of the Mooretown and the succeeding Beaver Bend limestone above it. Near the site of the old Croy's Mill, about 3 miles downstream, both the Mooretown and the Beaver Bend formations are present and are 21 feet and 10 feet in thickness, respectively, and the Paoli limestone there has a shale bed near the top very similar to that shown at the upper falls at Cataract. The Paoli limestone, the Mooretown (sandstone), and the Beaver Bend limestone are correlated with the Renault of the Illinoian Chester.

In the lower Cataract Falls the uneven contact of the St. Louis and Ste Genevieve limestones is clearly shown approximately 10 feet above the water of the plunge pool and 8 feet below the lip of the waterfall. Patches of angular chert occur at the very base of the Ste Genevieve, which is distinctly whiter than the gray and dark beds of the St. Louis. Five or 6 feet below the contact are numerous dark, silicified *Lithostrotion prolitherum;* and, just below water level, the thin-bedded, dense St. Louis limestone is studded with the small masses and dark balls of flint 1–2 inches in diameter so characteristic of the upper part of the St. Louis. No evidence of colonies of *Lithostrotionella castelnaui* (= *Lithostrotion canadense*) was observed. This index fossil of the upper St. Louis, restricted to a single bed or zone, usually occurs about 20 feet below the contact with the Ste Genevieve; hence its horizon is not exposed at the lower falls. Large masses of porous, fossiliferous chert occur in the Ste Genevieve 3–4 feet above the base on the south side of the waterfall bluff. These chert masses are very similar to the fossiliferous Lost River chert beds of the lower part of the Ste Genevieve farther south in Indiana. The Rosiclare sandstone adjacent to the lower falls and cascades has retreated some distance back from the walls of the limestone gorge, since this sandstone weathers readily by solution, leaving the fine sand grains free to slump and wash away. However, it shows sparingly at one or two places on the north side of the falls, at and above the road on the south side, and in the turn of the road on the east side of the stream about $\frac{1}{4}$ mile southeast of the lower falls.

The Rosiclare sandstone of the Ste Genevieve described in the Cataract Falls section is present in numerous sections through southwestern Indiana, both north and south of Cataract. It varies considerably in its physical characteristics and is rather erratic in thickness, ranging from a few inches to a known section as great as 38 feet. It usually occurs 30–60 feet below the top of the Ste Genevieve, which is well marked by a limestone breccia and the common occurrence of the rather thin Aux Vases sandstone. The constant presence of the sandstone at the same horizon throughout the area of the outcrop of the Ste Genevieve to the Ohio River has led to its outright correlation with the Rosiclare sandstone of the southern Illinois section rather than to the proposal of a new name for it.

THE NATURAL STEAM AT LARDERELLO, ITALY

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AND
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ABSTRACT

The natural steam (vents, soffioni) of the Larderello and adjacent regions in Tuscany, Italy, was used in the largest pre-war natural steam power-plant installation in the world. The boric acid and other mineralizers in the steam were exploited in a large chemical industry. Many wells were drilled to tap the emanations delivered through fractures from a probable batholith freezing beneath.

Pneumatolysis is at work on a grand scale. This geologic occurrence merits more attention from American (and European) geologists than it has received. Data collected on brief field visits during early partial rehabilitation of the plants following bombing and demolition are presented.

INTRODUCTION

The use of natural steam from subterranean sources for generating power is an intriguing geological and engineering development not commonly realized. However, in Tuscany, Italy, at Larderello, about 12 miles south of the town of Volterra, a large-scale exploitation of natural steam has been developed since 1904 to such a stage in 1941 that over 100,000 kw. of electric power were being generated. Moreover, large quantities (over 10,000,000 kg. per year) of boric acid, borax, ammonium carbonate, carbon dioxide, and other chemicals were recovered from the vapors. During World War II the installations suffered severely from bombing and demolition, but reconstruction began in 1945 with the hope that eventually the future plants will exceed those of pre-war times. Insufficient attention has been given in American geological literature[1] to this striking geological occurrence of a probable freezing subjacent batholith, and even the most authoritative Italian publications on the subject have not been generally known or circulated because they were privately printed.

The Tuscan locality outstrips by far any similar occurrence in the world. Of the others, Iceland magmatic heat has been piped to an airport landing field and into Reykjavik, New Zealand has potential energy in her geyser region, and the "geysers" region of California north of San Francisco offers meager possibilities for the utilization of magmatic steam by man, but these do not have the potentialities of the large-scale, pre-war development at Larderello.

The material in this report comes from a variety of sources. As much firsthand information as possible was obtained from two brief visits to the area while the senior author was on geology-teaching field trips from the United States Army University (University Study Center) at Florence, Italy, during the fall of 1945. Inquiries were made of employees at Larderello and members of the science faculty at the Italian University at Florence. Serious handicaps imposed by the physical de-

[1] E. T. Allen and Arthur L. Day, "Steam Wells and Other Thermal Activity at the 'Geysers,' California," *Carnegie Inst. Wash. Pub. 378* (1927), p. 100.

Sir Roderick Impy Murchison, "On the Vents of Hot Vapor in Tuscany, and their Relations to Ancient Lines of Fracture and Eruption," *Jour. Geol. Soc. London*, Vol. VI (1850), pp. 367–84.

struction (about 90 per cent of production) of the power and chemical installations by the Allied bombing and German demolition, the possibility of unexploded mines remaining on the premises, the scattering of the employee personnel, and the effect of the change in political complexion of the Italian nation prevented collection of much desired data. Omissions are noticeable, but the reader is asked to be tolerant because of these difficulties. If nothing more is accomplished than to stimulate interest in American geologists touring Italy to visit and study the soffioni this note is worth while.

Published data (sometimes in conflict with those obtained in interview) were obtained from the private brochures written by the Messrs. Conti and generously donated through the good offices of Professor G. Abetti. The chemical problems were discussed with Professor G. Mannelli and with Captain Ludwig F. Audrieth, United States Army, professor of chemistry on leave, University of Illinois. The junior author, besides contributing geological data personally obtained, gave indispensable aid in bridging the language barrier which otherwise would have made this report impossible.

LOCATION AND HISTORY

The natural steam vents of Tuscany occur principally in seven groups distributed over an elliptical area of about 100 square miles[2] which lies 12 to 20 miles south of the town of Volterra, and about 20 miles inland from the Tyrrhenian Sea (Fig. 1). The seven groups which have been exploited, each including an area of several square miles, are Larderello, Castelnuovo, Serrazzano, Lustignano, Sasso, Lago, and Monterotondo. The largest power production and the main pre-war chemical plant were located at Larderello, which has given the name to the organization, Società Boracifera di Larderello, that controls the entire area.

The natural steam vents or blowholes, called soffioni, have been known since the thirteenth century when they were avoided as dangerous manifestations of satanic power. After about 1750 a beginning was made in the study of the geology of the region, and in 1777 Hubert Höfer, a chemist in the service of the Grand Duke of Tuscany, discovered and isolated boric acid from the waters issuing with the natural steam from the soil. Paolo Mascagni confirmed the occurrence of boric acid in 1799, but an independent boracic industry was not established until after 1827 when Count Francesco Larderel, a French exile, conceived the idea of utilizing the steam to concentrate the aqueous boric acid solutions. This proved successful, and the Larderello development was named in honor of Count Larderel.

Heat from the steam was used in various other stages of chemical industrial development, but no attempt was made to use it for generating power until 1904. Prince Piero Ginori Conti, then general director of the Larderello works, on July 4, 1904, fed a small steam engine with the natural steam and drove a small dynamo which lighted a few lamps. Conti was assisted by Professor Nasini of the University of Pisa and by Signor Ingegnere Bringhenti, who determined from measurements in 1905 that the steam issuing from the soffioni is superheated and maintains a practically constant temperature at a given output. Conti installed a larger steam engine in 1905, further enlarged the power plant with a turbine in 1912, and continued to add equipment at later dates.

[2] Prince Piero Ginori Conti, *The Natural Steam Power Plant of Larderello* (Firenze, Italy: Privately printed, 1924), p. 8.

A serious problem in power generation was presented by the abundance of gases other than steam which made condensation of the engine exhaust inefficient. Beginning in 1912, the natural steam was used to heat pure water whose steam was fed to the engines and then conventionally condensed. This procedure was continued until 1923 when Signor Bringhenti devised apparatus by which about 90 per cent of the contaminating gases were removed from the steam at only slight loss of temperature. By making appropriate adjustment in the condensers it was found more efficient to feed the processed steam directly to the engines than to continue the secondary evaporator stage; therefore, the Bringhenti process is still utilized.

The chemical industry which started with Höfer in 1777 with the production of boric acid and borax ("sale sedativo di Homberg" and "Tinkal," respectively) has evolved and grown along with the power developments until a dozen or more chemicals in different grades were manufactured at Larderello before the war. The 658-page treatise on the Tuscany boracic industry by Raffaello Nasini[3] and his students in chemistry is a monument to Nasini and an adequate expression of the researches and developments made on the chemical side.

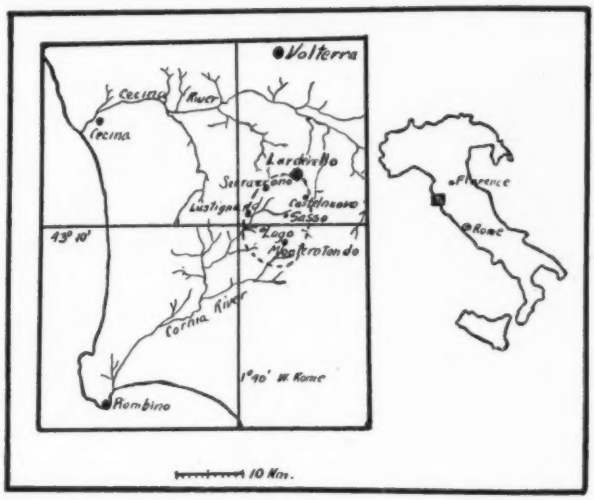

FIG. 1.—Location of Larderello and the soffioni area (modified after Conti)

GEOLOGICAL AND OTHER TECHNICAL DATA

The hot springs and bubbling puddles (lagoni), the steam vents (soffioni), and the drilled wells of notable vigor (soffionissimi) of Tuscany occur between the Cecina and Cornia rivers in a region of generally mature topography (Fig. 2). Surface rocks are mainly sediments of Eocene to Miocene age: limestones and shale at Larderello, sandstones at Sanno and Lago, limestone with chert at

[3] Raffaello Nasini and Students, *I soffioni e i lagoni della Toscana e la industria boracifera, Associazione Italiana di Chimica* (Firenze, Italy: Publication sponsored by Piero Ginori Conti, 1930).

Monterotondo, but serpentine at Serazzano. The serpentine is probably a transported exotic in the Argile Scagliosa formation (Tertiary) which has been interpreted by Migliorini[4] as being tectonic rubble. Giovanni Conti[5] has emphasized

FIG. 2.—The power plant and chemical works at Larderello. Under normal operation all the steam would be utilized rather than blown into the air at the well locations.

that neither the age nor lithology of the surface rock influences the location or production of the steam. One expects rather that the positions of deep-seated faults determine these factors. As early as 1850, Murchison[6] reported that the vents issued along "ancient parallel lines of fracture," and De Stefani[7] later confirmed this conclusion. The present writers spent insufficient time in the field to work out the details of the structure in the region, but from a review of the large-scale geologic map and drill cores in the office at Larderello they sustain the belief that the steam arises along post-middle Tertiary faults. Local diversion of the steam by shallow fractures and divisional openings in the surficial rocks has probably widened the productive area above the deeper faults.

Conti[8] wrote of "making hundreds of drillings in the last twelve years" (pre-

[4] Personal communication, fall 1945, from Carlo Migliorini, professor of geology, University of Florence.

[5] Giovanni Ginori Conti, *Utilizzazione dei soffioni boraciferi* (Firenze, Italy: Privately published, 1936), p. 77.

[6] P. 367 of ftn. 1.

[7] De Stefani, "I soffioni boracifera della Toscana," *Memorie della Società geografica Italiana* (1897), VI, 2, 410.

[8] P. 73 of ftn. 5.

ceding 1936) totaling about 40,000 meters in length, but conversation with staff members on the ground indicated that only about one hundred wells were significantly productive. Most wells were drilled about 250 meters deep, but the deepest reported was about 550 meters (literature) or about 900 meters (conversation with employees). Drilling had been done with both churn and rotary equipment, and an extensive expansion program was in progress when the war started. Up to that time increased drilling had not lowered steam production. Definite information on the distance or patterns of spacing of wells was not available, but casual observation indicated a generally linear arrangement with holes separated several hundred feet.

TABLE 1

DATA ON A REPRESENTATIVE LARDERELLO WELL

Data	Metric	English
Diameter	480 mm.	19 in.
Depth	247 m.	876 ft.
Pressure	4.5 kg. per square centimeter	63.5 lbs. per square inch
Temperature	205° C.	410° F.
Yield	220,000 kg. vapor per hour	485,000 lbs. vapor per hour

Representative data of a well completed on March 26, 1931, are given in Table 1.[9]

Although most wells deliver steam at pressures from 2 to 5 atmospheres, one well was rated at 14 atmospheres with the valve partly open (Fig. 3). Probably the pressure on the closed well would have been higher, but it was considered unsafe to close it off entirely. Conti[10] reported that Nasini's experiments showed "that the steam issuing from the Soffioni is superheated. . . . . I cannot give any satisfactory explanation regarding the causes of this superheating."

FIG. 3.—Natural steam escaping at approximately 4 atmospheres pressure from about an 18-inch pipe. The noise was deafening—note hands over ears of observers.

Allen and Day[11] explained similar superheat of the "geysers" in California, "This seems to mean that the steam as it rises from the depths is superheated and becomes saturated only after it has stood under pressure in the wells—probably because of the condensation of a portion of steam."

The steam from many wells is fed in to "supercentrali" power plants which had

[9] Personal communication from Professor G. Mannelli and Captain L. Audrieth, November, 1945.

[10] P. 13 of ftn. 2.

[11] P. 62 of ftn. 1.

a capacity of over 100,000 kw. in 1941. During 1938 a total of 202,610,000 kwh. of electricity was reported generated by the passage of 6,263,400 tons of steam through the plants. This power served most of the consumers in Tuscany and supplied the major need for the electrical railways between Livorno (Leghorn) and Rome. War destruction had cut the power production in late 1945 to about 10 per cent of pre-war capacity. Two large condensing towers intact and one demolished by bombing are shown in Figure 4.

In practice, the boric acid is removed as a dilute solution in condensed steam and then further concentrated by evaporation. In subsequent stages the CO_2, NH_3, H_2S, etc., are taken out of the vapor. They may be purified and selectively recombined to produce a variety of carbonate or ammonium compounds. The details of the chemical processes and researches fill a volume (Nasini) in themselves.

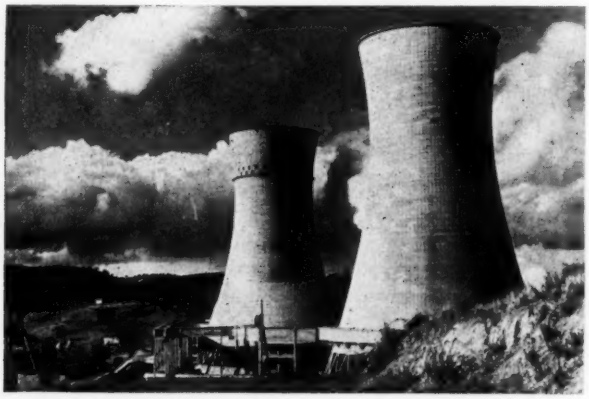

FIG. 4.—Two large condenser towers and the lower remnant of one destroyed by bombing

The chemical industry which started with the recovery of boric acid from the vapor was elaborated before the war to recover most of the "impurities" in the steam. The composition of the vapor, which is remarkably constant over the entire area and which has remained so despite continued drilling, is given[12] in Table 2. An analysis of the steam from well No. 2 of the California "geysers" locality[13] is included for comparison.

The gas residue, after condensation of the water vapor and elimination of boric acid and ammonia, is, according to Audrieth[14] and Mannelli, as shown in Table 3.

Annual production in the 1936–38 biennium ran about 7,000 to 8,000 tons for boric acid, about 4,500 tons for borax, and about 400 tons for ammonium sulphate. Other chemicals manufactured at Larderello include carbon dioxide and "dry ice," liquid ammonia, ammonium carbonate, ammonium bicarbonate, sodium perborate, ammonium chloride, manganese borate, and boron carbide.

The economic importance of these

[12] P. 64 of ftn. 3.

[13] Allen and Day, p. 76 of ftn. 1.

[14] Personal communication, 1945.

emanations justified a comprehensive geological and geophysical research program which was well under way prior to the war. A large-scale, highly detailed geologic map had been drawn of the thermal area, and drill cores taken from certain wells have been mentioned earlier in this report as surviving the ravages of war. Conti[15] reported the construction of a three-dimensional geological model from drilling data. A net of precise levels had been run to permit detection of any earth movements in the area. Gravimetric surveys were run using both a Sterneck pendulum and an Eotvos balance. Magnetometric data were collected. Preliminary earth-resistivity measurements using the Wenner method proved sufficiently interesting to stimulate additional research. The results were to be published when they were more complete. A local seismograph station was equipped with double horizontal-component apparatus and with two different vertical-component instruments having low and high sensitivities. When the war damage has been repaired it is hoped that these research programs will be continued.

TABLE 2

GRAMS PER KILOGRAM OF NATURAL VAPOR

Natural Vapor	Larderello	California Well No. 2
H_2O	945.87	986.86
CO_2	51.86	7.77
H_2S	0.86	0.35
H_3BO_3	0.5	less than 0.04
N_2	0.46	0.35 N_2 + A
CH_4	0.34	2.08
H_2	0.05	2.16
NH_3	0.1	0.18
He, Ar, etc.	1.0 cc. per kg. (with N_2)	

[15] P. 74 of ftn. 5.

SOURCE OF THE STEAM

The source of the steam and gases of the Larderello region seems without much doubt to be magmatic. Ground water probably contributes some to the steam, but without the thermal energy of a magma there would be no soffioni. The Italians have attached high significance to the abundance of boric acid as a diagnostic characteristic. As early as 1897 De Stefani[16] pointed out that boric acid is not found in the superficial strata except when introduced locally and secondarily; its home is in the ancient granites. The high temperature and constant composition of the emanations also indicated that they were magmatic. Later D'Achiardi[17] elaborated on a possible source of the boron in (1) hypothetical deep-seated boron carbide or sulphide, (2) decomposition of borates of sedimentary origin, (3) borosilicates in serpentine, (4) tourmaline in granite, and (5) a product of volcanic (eruptive) fumaroles. He considered these hypotheses untenable and concluded that the soffioni were "vulcanico-geyseriania."

TABLE 3

PER HUNDRED LITERS OF GAS

CO_2	93.0 liters
H_2S	2.4
H_2	1.8
CH_4	1.8
N_2	1.0
He, Ar, etc.	about 3 cc.

The following facts are significant in convincing the writers of a magmatic source for the steam in Tuscany:

[16] P. 410 of ftn. 7.

[17] Giovanni d'Achiardi, "Considerazioni critiche sulla origine dell'acido borico nei soffioni boriferi della Toscana," *Mem. Soc. Tosc. Sc. Nat. Pisa*, Vol. XXIII (1907), and "Guida al corso di mineralogia," *Pub. Francesco Vallardi Milano* (1925), p. 98.

1. Steam with superheat.

2. Steam pressure of at least 14 atmospheres.

3. Great volume of steam not affected appreciably by extensive drilling.

4. The abundance of boric acid and other mineralizer substances in the emanations.

5. The occurrence of the steam in large quantity distributed in localized areas over a district of about 100 square miles.

There seems to be little need to expand or elaborate the above evidence for magmatic origin. Some interesting speculation may be projected beyond the facts at hand. Perhaps a granitic batholith which has been freezing throughout a long period lies beneath Tuscany. The soffioni areas may be localized above cupolas if the cupolas are associated with faulting in the roof of the pluton.

$$\frac{100 \times 6{,}260{,}000 \times 2{,}000}{6 \times (5{,}280)^3 \times 2.67 \times 62.5} = .008 \text{ approx.}$$

From the figure of 6,263,400 tons of steam used for power in 1938 an approximate value of a minimum rate of solidification can be computed for the magma. Assuming that the magma contains 6 per cent[18] water in solution and taking a value of 2.67 for the density of granite and 62.5 pounds as the weight of one cubic foot of water, then approximately .008 cubic mile of frozen magma could supply the steam which was tapped in 1938 if the magma's entire water content became tapped steam.

About $5\frac{1}{2}$ cubic miles of granite, a small part of a pluton underlying an area of 100 square miles, could on the same assumption have furnished steam at the 1938 commercial rate for the 700 years of known activity. But most probably much more steam was released and dissipated through the rocks between the soffioni localities than was tapped by the wells. Moreover, the figure of 6 per cent for volatiles dissolved may not be correct in this case, and the computation may be far in error. It would be interesting to repeat solubility experiments like those of Goranson, using the Larderello emanations in place of pure water. Students of rock alteration and of mineralizer solutions should find the Larderello region one of fruitful interest.

If this region is underlain by a pluton now partially frozen, a spread of seismic prospecting shots taken over it might possibly reveal something of the size of the solidified top or the behavior of seismic waves within a possibly still-liquid interior. Perhaps other information pertinent to the general problem of batholiths might be obtained here. The authors believe a most significant geologic occurrence has escaped the attention of most American geologists.

[18] Roy W. Goranson, "The Solubility of Water in Granite Magmas," *Amer. Jour. Sci.*, Vol. XXII (1931), pp. 481–502.

GLACIATION IN THE DESERT RANGES, UTAH

RONALD L. IVES
Dugway Proving Ground, Tooele, Utah

Ground and aerial reconnaissances in the desert-range area of Utah, comprising parts of Box Elder, Tooele, Juab, and Millard counties, disclose clear evidence of glaciation in only three ranges; some doubtful and contradictory evidence of ancient ice erosion or more recent nivation in several others; and no evidence of either glaciation or nivation in the remainder.

Typical and reasonably well-developed moraines are present in the Deep Creek Range and its extension, the Snake Range. Two sets of moraines are present in various valleys draining the slopes of Haystack Peak (Deep Creek Range); some scanty evidence suggests a third glaciation of much greater age. Wheeler Peak and Mount Moriah (Snake Range) were definitely glaciated, rough reconnaissances indicating two ages considerably separated in time. The younger glaciations in this general area are tentatively assigned to the "Later Epoch of Glaciation."[1] A thorough study of this area should be productive.

Poorly developed moraines, nivation scars, and several types of solifluction ridges are widespread in the Oquirrh Range. Most of this evidence seems older than that from the Deep Creek Range. Much of it leads to somewhat uncertain conclusions, suggesting surficial rearrangement, possibly due to frost action during relatively recent periods of increased precipitation.

One poorly preserved moraine, of apparent great age, deeply eroded and probably altered by faulting, is present on the southwest side of Deseret Peak (Stansbury Range) at an altitude of about 8,500 feet. Nivation and solifluction occurred in many places in the Stansbury Range and in its southern extension, the Onaqui Range.

Scattered evidence of nivation and solifluction was found in the Cedar, Newfoundland, and Thomas mountains. None of this evidence is clear or well developed. No evidence of glaciation or related processes was found by either aerial or ground reconnaissances in the Silver Island, Lakeside, Dugway, Fish Springs, Confusion, House, and Drum mountains; or on Granite Peak, Wig Mountain, Wildcat Mountain, and Stansbury Island.

Areas are named according to the General Land Office Map of the State of Utah (1937, 1 inch = 12 miles). Ranges not listed by name were not visited in connection with this reconnaissance.

[1] W. W. Atwood, "Glaciation of the Uinta and Wasatch Mountains," *U.S. Geol. Surv. Prof. Paper 61* (1909), pp. 1–15, Pl. I.

REVIEWS

Varvity in Danish and Scanian Late-Glacial Deposits; with Special Reference to the System of Ice-Lakes at Egernsund. By SIGURD HANSEN. ("Danmarks Geologiske Undersøgelse," II. Raekke, Nr. 63.) Copenhagen, 1940. Text, pp. 1–411 in Danish, pp. 413–78 English summary; figs. 20. Atlas of 45 plates and 2 maps.

The glacial clays in Denmark and southwestern Scania, the southernmost province of Sweden, were intermittently studied by Baron Gerard de Geer during 1906–17 and by the reviewer in 1918–20, but we were baffled by their poor, thin, and irregular lamination. However, since many lamina couplets fully resemble thin unquestionable varves, De Geer was convinced that most or all of them actually were varves and published graphs in 1926 and later. "Varve," "varvity," and "varved," it may be recalled, denote "annual deposit," "year-lamination," and "annually laminated." Geological conclusions based on these supposed varves met with strong opposition from Danish geologists. In 1927 the young Danes, Sigurd Hansen and S. A. Andersen, began to investigate these clays, after having studied geochronology under De Geer in Stockholm in 1925–26. Both Andersen and Hansen independently soon came to the conclusion that most of the lamina couplets measured by De Geer and me as varves represented only days or weeks (p. 422). Both published short papers, and Hansen undertook the detailed and comprehensive investigation quoted above.

The glacial clays in Scano-Dania were deposited in lakes and in the sea. The lakes were of two main kinds: glacial hillock lakes and marginal or regular glacial lakes (pp. 426–28).

The glacial hillock lakes are recorded by laminated clays occurring on top of the highest hillocks. The clay is called *Bakkeler*, *platålera*, and *Deckthon* and will here be named "hillock clay." The ancient level lake floors in a region rise to about the same heights, usually 5–20 meters above the surrounding land. The laminated clays are mostly a few meters thick, but some are as much as 10 meters. They rest normally on boulder clay, which forms the bulk of the hillocks. These are steep-sided and range from 100 meters to 4 km. in diameter. They occur in or just behind a morainic belt of knob-and-kettle topography or from 1 to 20 km. behind a marked ice border. The lakes were evidently ponded on all sides by ice and were windows in the ice, which must have been stagnant, though perhaps not broken into blocks. The cause of the melting of the windows over the highest hillocks is not known (p. 80).

The marginal ice lakes were dammed on one or more sides by ice, and a few may have been surrounded by ice. Some of these ancient lakes occurred in topographic basins, others did not (p. 84). Size, shape, and duration evidently varied. None of the Danish lakes seems to have exceeded 20 sq. km., while the glacial lake in central Scania was much larger and that of the southern Baltic was huge.

"Meltwater lakes"—regular lakes fed by meltwater from a glacier at some distance—are not surely recognized by Scano-Dania, but normal cold-temperate lakes, which received no meltwater, were present (p. 431). These were only lakelets or ponds. The surrounding arctic vegetation being sparse, mud was washed into the lakelets to form downwash clay (*Dryas* clay, *Anodonta* clay).

Hansen distinguishes two main types of ice-lake clays, A and B (p. 444). Type A is water-laid and stone-free but massive. Type B is stratified or laminated; a subtype is varved.

The massive or symminct clay, type A, occurs at only a few places (pp. 444, 445, 466). It was clearly a result of as fast settling of the fine particles that remained in the lake as of the coarse ones, and the problem of its formation is as follows: Why did all the fine clay, of which there must have been plenty dispersed through the lake water, settle before winter, so that not even a thin winter layer formed? Generally, symminct structure is a consequence of a high concentration of electrolytes; and it probably was also so in these cases. It is significant that these lake clays are more symminct than are the marine and brackish-water clays in Scano-Dania. Of the latter clays, most are stratified but unvarved, some are varved (locs. 136, 137,

142, 145, and 146), and a few are almost massive (locs. 130, 133–35).

Type B, which is laminated and, in Hansen's opinion, sometimes varved, embraces most of the glacial-lake clays in Scano-Dania. Two principal types of varvity are recognized. One, called the "normal" type or "Egernsund" type, is characterized by a greasy, conspicuous winter layer and a summer layer, which is several times thicker and mostly laminated. The varve thickness is usually 5–15 cm. (p. 469). This type is present in glacial Lakes Egernsund (several of locs. 1–23; Pls. 1–13, 35, 36) and Stenstrup (loc. 50; Pls. 18–20, 37, *L* and *M*), and at localities 43 (Fig. 32, Pl. 37, *J*), 47 (Pl. 37, *K*), 70 (Figs. 44–46), 86 (Pl. 26), 109 (Fig. 54, Pl. 38, *R*), 136 (Pl. 29; pp. 459, 470), 137, and 142, the last three deposits being brackish-water clays.

The glacial clays in the Egernsund region (Pls. 1–13, 35, 36, *E–H*), which are unquestionably varved, show within each varve irregular, mostly faint, laminae which probably were caused by small variations in currents and mud supply. Such faint laminae are regular features in varves formed near the point of mud inflow. Occasional laminae are prominent and comparable to similar ones in Lake Stenstrup. The clays of glacial Lake Stenstrup (Pls. 18–20, 37, *L* and *M;* pp. 241, 243) in which De Geer, Andersen, Hansen, and the reviewer apparently recognized the same units as varves, show, notably in the summer deposits, both faint and distinct laminae. The small and faint ones seem to be comparable to those common in the Egernsund clays. Light streaks of silt in the winter layers record influxes of mud after the colloidal clay had begun to settle in the early winter. On the other hand, the prominent light and dark couplets, such as those in varves 5 and 6, Figure *L*, and in varves 12 and 13, Figure *M*, many of which resemble thin varves, are not so readily explained. Each lamina couplet suggests a distinct inflow of mud, dispersion of the mud in the lake, and its separation by differential rates of sinking. The light, coarse fractions settled during and/or after the mud influx, depending on its duration; then the fine particles formed the dark lamina before any new large mud inflow took place. Judging from Figures *L* and *M*, there were mostly five to seven major influxes in melting season, or an average of one every 4–7 weeks, if this season comprised 7–8 months. The large temporary mud influxes could have been due to periodic ice melting or, more probably, to intermittent discharge into the lake of the main feeder stream, which much of the time then would have been diverted from the lake because its channel or tunnel was blocked by accumulated debris or collapsing dead ice.

Although the clay in the dark laminae probably is coarser than that in winter layers, it is not well understood how the clay laminae could form in the relatively short space of a month. Clay particles settle very slowly in ice-cold water because of its high viscosity; and, since the lake was ice-dammed, its temperature could not have risen much without causing its own destruction. The separate deposition of the relatively coarse fraction of the mud indicates low concentration of electrolytes. On the other hand, the water depth of some 20 meters (p. 252) was relatively small. Also, the amount of suspended fine mud was probably large, and the rate of sedimentation is proportionate to this quantity. Even though this attempt at explaining the marked laminae may be inadequate, these are surely subdivisions of varves, and the varvity recognized by Hansen seems certain in the clays of the listed deposits.

The second, so-called "zonary type," of varvity is defined by Hansen to comprise varves that have a lamination in the autumn and winter part as well as in the summer part and that are 2 dm.–1 meter thick (p. 470). It thus comprises clays having both a marked lamination by alternation of silt or fine sand and clay and a stratification of the second order, a zoning. The laminae range in thickness from mere streaks to 1.5 cm.; the couplets of silt and clay, which may resemble true varves in the grading of the material, measure up to 2 cm. (pp. 269, 454; Pl. 38, *N*). The zoning is produced by alternation of predominantly silty and of largely clayey beds, each consisting of a few to many couplets of laminae. The silty zones range from thinner than the clayey zones to several times thicker. The clayey zones vary in general composition from silty clay to fine clay. It is pairs of these zones, 2 dm.–1 meter thick, and comprising up to 75 lamina couplets, which Hansen regards as varves and recognizes at localities 29, 53, 59, 62, 76, 96, 145, and 146.

The zone pairs in some clay deposits are unquestionably varves. This holds foremost for those of localities 96 (Pls. 27, 38, *Q;* p. 309), 76, *D* (Fig. 48; p. 289), and 146 (Pls. 31–34). The first two were probably formed in marginal lakes; the last was deposited in brackish water.

At locality 96, Andersen and the reviewer had earlier measured the same couplets as varves.

Most other clays with zoning raise the question: Are the prominent varvelike lamina couplets, or are the zone pairs varves?

At locality 59 (Figs. 40–42; p. 264) there are thin marked laminae of silt or fine sand and clay, clay making up a little more than half. Especially when the clay is semidry and is viewed from a distance, a beautiful zoning is also visible. The clayey zones are as thick as, or thicker than, the silty zones, a pair averaging 3 dm. There seem to be 12–15 zone pairs in the deposit. In one case the silty zone contained 15–20 lamina couplets, the clayey one, 30–40 couplets. The silty zones may represent periods of relatively heavy inflows of mud, during which much of the fine fractions passed through the lake; the clayey zones, periods of smaller inflows during which most or all of the clay settled in the basin. The clay deposit forms the top of a relatively large hillock.

At locality 62 (Pl. 38, *N;* pp. 269, 454) there are distinct laminae of fine sand or silt and of clay. The material is well assorted and graded within the couplets, so that many of these resemble true varves. The thickest couplets measure 2 cm., of which 3–4 mm. are clay. There is also a subordinate, faint, and minute lamination. The zone pairs in this clay really resemble exceptionally thick varves, the clayey zones being distinct and relatively thin. The zone pair which is called "varve No. 5" by Hansen contains about 60 lamina couplets in the sandy zone, 30 cm. thick, and 15–20 in the clay zone, 6 cm. thick. At least 40 of the couplets in the sandy zone are varvelike. The clay deposit forms the top of a hillock, which is 300×400 meters in extent and rises 15 meters above its surroundings. It is 4–6 meters thick and contains probably 12–13 zone pairs.

The distinct lamina couplets at locality 62 were regarded as varves by De Geer (p. 423). In favor of well-developed couplets being varves is their resemblance to thin, true varves by the assortment of the material, its grading in a couplet, and the abrupt termination of the clay upward. Against their being varves are several conditions. They are not sufficiently distinctive but grade into pairs of faint streaks of light silt and dark clay which cannot be varves. The resemblance to varves might be largely superficial in that the dark lamina might consist of much coarser clay than do winter layers of varves; no comparative analyses have been made. That this is actually the case is suggested by the general coarseness of the material, considering the small thickness of the couplets. Varves so thin should consist of finer material. There are probably well over 700 varvelike couplets at locality 62. If these lamina couplets were varves, what prominent periodicity of 40–75 years would they record? What would the zone pairs signify?

Well-developed zone pairs such as those shown in Figure 42 and Plate 38, *N*, resemble exceptionally thick varves. The clayey zones frequently or normally have a marked upper limit (pp. 265, 269). The zoning represents a periodicity as distinct as the year. Considering that in the finer sediments of glacial Lakes Egernsund and Stenstrup the varves are mostly 7–10 cm. thick, the zone pairs can very well represent the annual deposit (p. 269). Varvelike lamina couplets occur in varves of the mentioned lakes (Pls. 36, 37). On the other hand, while the number of the varvelike couplets within a varve of Lake Stenstrup is but 5–7, it is some 40–75 at localities 53, 59, and 62. In the silty zone of zone pair 5, locality 62 (Pl. 38, *N*), there are about 40 major lamina couplets. Too few to record the day-and-night period, as Hansen believes (p. 270), each couplet would, instead, represent at an average 5–6 days, if the melting season was 7–8 months. At locality 59, the 15–20 lamina couplets in the silty zone and the 30–40 couplets in the clayey zone would mean a brief summer and a long autumn-winter with many moderate inflows. Either inflows would have occurred intermittently the year round, or no colloidal clay remained in the lake to settle in the winter; it could have been carried away by the outflowing water. The lamina couplets in localities 53 and 59 would have formed at a rate of 1 in every 5–7 days throughout the year. What marked climatic period could this be that caused, first, inflow of mud, then practical cessation of inflow, permitting the clay to settle? Or how could the influx be so periodic if intermittent by repeated diversions of the main feeder? How could varvelike couplets form in the short space of 5–7 days?

In making the choice between the lamina couplets and the zone pairs as varves, the coarseness of the material, the probable length of life of glacial hillock lakes, and the small depth and size of the lakelets should probably weigh most heavily. The two former speak against the lamina couplets being varves; depth

and size favor zone pairs. Thus coarse material goes with thicker varves than the lamina couplets. The tiny hillock lakelet of locality 62 could not well have existed for over 700 years. It does not occur in a prominent morainic line. An ice border is stationary because supply and wastage balance each other. The large Salpausselkä moraines of southern Finland represent, according to Matti Sauramo, only 660 years. The lamina couplets can hardly be varves. The zone pairs must represent the annual deposit, as Hansen holds.

The zone pairs are varves of an extraordinary type, associated with the peculiar mode of dead-ice waning in Denmark, southwestern Scania, northern Germany, and the East Baltic countries. The intermittent mud supply of the lakelets can have had at least two causes. It can have been a consequence of changing weather, such as warm spells followed by cold ones and rains followed by dry weather (p. 270). The day-and-night period seems too brief and would postulate many more lamina couplets than are present. The intermittent mud influx can also have resulted from temporary diversions or changes in the course of the supply stream.

The distinct lamination and the great number of the couplets postulate a thorough and rapid separation of the glacial mud into silt or fine sand and clay and a prompt deposition. The surprisingly quick settling of the clay fraction is at least partly explained by its relative coarseness and by the small depth of the lakelets. It may have been partly a consequence of large quantities of suspended material. But further studies are needed.

Decreasing distinctness of the annual stratification in Scano-Danian clays produces transitions to mere lamination. At localities 53 (Fig. 39) and 145 (Fig. 58) there is indistinct, at locality 76 (Fig. 47) doubtful, zonary varvity. At locality 82 (Fig. 49) there is a trace of zoning. At localities to be discussed below no varvity can surely be distinguished. The variation from distinct to unrecognizable varvity may depend mainly on the amount of fine clay that remained to settle in the lakelets during the winter (and autumn) (p. 384). This amount, in turn, depended on the quantity present in the inflowing glacial mud, on the portion that settled in the lake during the summer, and on the part that left the lake with the outflowing water.

Among the many clay deposits classified by Hansen as laminated but unvarved are localities 34, 94, and 95. All three deposits occur on top of hillocks. At locality 34 (Fig. 31, Pl. 36, *I;* p. 221) the clay contains laminae of rather coarse, rusty sand, which come out black on the photographs, but no strata that can be interpreted as winter layers. Locality 94 (p. 304), Maarum, is a hillock clay, 0.5×1.5 km. in extent, located in a marked morainic belt. The clay is beautifully laminated by alternating fine sand or silt and clay. At one place, where the clay is 6 meters thick, the couplets average 2 mm., so there may be some 3,000 of them. Hansen found no winter layers and no sure zones. De Geer has published 1,400 lamina couplets as varves; but it is extremely improbable that such thin and coarse couplets represent the year and that the hillock lakelet could last 1,400 years, not to say 3,000. Locality 95 (Pl. 38, *P;* p. 306), Dønnevaelde, is a hillock clay which is 300×400 meters in area and located in the same morainic belt as the preceding site. As seen in the photograph, the clay has beautiful lamination of at least two orders. Major couplets are marked by prominent dark clay laminae and are 0.5–1.5 cm. thick. In most of the coarse major laminae there are minute laminae, just as in some of those at locality 62 (Pl. 38, *N*). The major couplets were, in 1919, measured by me as varves, 100 of which were published by De Geer in 1935. However, since there may be as many as 600 major couplets in the clay, which is 6 meters thick, and since they resemble the short-term couplets at locality 62, they may not be varves.

Varves gradually decrease in thickness from the point of discharge of the glacial mud, and in large glacial lakes their distal portions may be only a few millimeters thick. The clays at localities 111 and 112 (Fig. 55; p. 322) in southeastern Scania are probably such distal varved deposits of the large glacial Baltic as De Geer recognized. The occasional layers of sand may be of local origin and caused by wave wash.

Hansen concedes varvity only at De Geer's localities in Lake Stenstrup and at Dronningmølle (Hansen's locs. 50 and 96; pp. 25, 254, 418, 451) and thus finds that the Swedish clay chronology at present terminates in northeastern Scania and that the prospects of extending it backward to Jylland and northern Germany are extremely slender (p. 474). Since most Danish glacial lakes seem to have existed for only 10–20 years, while Lakes Egernsund and Stenstrup lasted for about 50 years (pp. 446, 453) and since there is no positive evidence for

centuries—long halts in the retreat, Hansen estimates that the ice recession from the East Jylland moraine, the correlative of the south Pomerania stage, to northeast Scania took 2,000–3,000 years at the very most (p. 475). Since the ice border was in northeastern Scania about 13,500 years ago, the outer Pomerania stage would be dated at roughly 16,000 years. The belt being about 300 km. wide, a direct recession would have averaged 100–150 meters a year. However, the repeated oscillations of the ice border, which can represent long ages, make Hansen's time estimate seem rather low. The clays may be unreliable time indicators, since the ice-dammed lakes can have filled with sediments or can have disappeared before the ice really left the region. But, if Hansen's estimate is nearly right, a revision will be necessary of the reviewer's correlation between the ice waning in North America and in Europe (*Geol. Survey Can. Mem. 168* [1931], p. 33).

Dr. Hansen is to be complimented on the conclusion of the difficult and time-consuming study of the Scano-Danian clays. He and Andersen seem to have discovered the true natures of their different stratifications, and Hansen has logically applied the principles found to a great many clay deposits and has synthesized the findings. When the conditions of formation of these clays become better known through further physical and chemical laboratory tests (pp. 463, 467), they should, together with Hansen's wealth of data, give new important suggestions on the climate and the mode of ice waning in this exceptionally interesting zone.

ERNST ANTEVS

Geology Applied to Selenology. By J. E. SPURR. Lancaster, Pa.: Science Press Printing Co., 1945. Part I: pp. x+112; figs. 23, pls. 4; Part II: pp. xiii+318; figs. 72, pls. 10.

Spurr's *Geology Applied to Selenology: The Imbrian Region of the Moon* appeared early in 1944, and a similar detailed study of another limited moon area had been contemplated by the author. But, as no other region proved so well fitted as the one already studied, he decided to consider the moon's surface as a whole in a more general analysis of its typical features. These two studies are now printed as independent volumes under one cover: I, "The Imbrian Plain Region of the Moon," and II, "The Features of the Moon."

"The surface of the moon as shown in photographs displays phenomena which are related to phenomena that we describe as vulcanicity on the earth. They are sufficiently like those of the earth to be recognized as due to somewhat similar causes, while in their differences they illustrate the differences between the two bodies" (Part I, p. x). This basic idea really guides the investigations, although, because the differences between the two bodies are so great, the author strives to approach the lunar problems without preconceptions. Working inductively, he reaches conclusions and develops interpretations principally from his own observations. But, committed to volcanological explanations, he gives no attention to the alternative hypothesis that the moon's depressions and much of its surface configuration have resulted from impacts of colliding bodies, except as this hypothesis is considered and found wanting in a two-page addendum to Part I and in a single-page addendum to Part II.

Spurr arranges the moon's depressions into four groups, from largest to smallest: maria, cirques, caldera-craters, and blowhole craters. These are carefully described in an analytical way and naturally furnish much of the material for the dynamic interpretations and inferred lunar history. Much study has been devoted to the patterns of the craters to bring out ground-plan characteristics, the distribution of ejectamenta, and other related features. The outlines of many of the cirques and caldera-craters are found to diverge from the circular or elliptical toward a polygonal shape, and a genetic significance is seen in the tendency toward the hexagonal form. The blowhole craters, however, form perfect circles.

Faulting has also received much attention, particularly (1) concentric faulting on crater rims, (2) transverse faulting radially outward from the Mare Imbrium, and (3) graben faulting. Especially interesting and instructive is the Imbrian fault system, which is represented graphically on an analytical chart.

The reader is conscious of going over a great deal of local, though essential, factual material; but interwoven with the descriptive detail is the author's interpretation. Explanations are not deferred while facts pile up. Consequently, as the treatment progresses from one area to another, the similarity of phenomena necessitates considerable overlapping discussion. This, however, is inevitable at the present stage of

selenology when the broader basic facts are still in the process of being recognized.

Assuming, first, a completely liquid moon, Spurr lists in his résumé a succession of fifteen changes, or stages of events, in its subsequent history. Greatly simplified, the interpreted sequence is about as follows:

In a thickening silicious crust many (largely meridional) fissures formed partly because of contraction. "On a large scale, these fissures became indurated, probably silicified, as to their walls, by deposition from escaping gases and other solutions. A vast number of craters formed between these fissures, using them as walls, and thrusting them aside in their growth" (p. 305). With continuation of the induration process and shrinkage attendant on crateroid activity, the lines and zones of induration yielded least, developing "knife-edged" septa and fissure ridges and forming the structural pattern which has been called the "Primitive Complex."

Other systems of intersecting faults and fissures developed, between which blocks of crust were uplifted, followed by subsidence. Some blocks subsided with little preliminary uplift. "This process resulted in graben and graben-craters, and, by development into the more nearly circular forms, in great craters, which were nevertheless genetically like the polygonal forms."

"The graben-crater period immediately preceded and accompanied the gradual rearing of the great Imbrian dome; and toward the central portion of this uplift the suppressed gas-charged lava (lunava) drifted. This lava migration involved shifting heat, which in some regions brought about the beginning of the extended general period of remelting. As the dome grew, there developed radial faulting in and around it." The center of the Imbrian dome later collapsed, forming the Imbrian basin. The rim, of mountainous proportions, settled, depressing also the crust outside and thus producing a marginal outer trough into which mare lava flowed. "While the mare lavas (lunavas) were still fluid, there were formed, in the now cooling or cooled remelted areas and elsewhere, abundant 'immature' caldera-craters and dish-craters; and, especially near the mares, some mature caldera-craters" (p. 306).

"The mare lunava gradually attained a crust. The crustal depressions or basins, especially those south of Imbrium, which depressions had been filled with lava and had already crusted over, experienced a further renewal of depression or sinking which broke the earlier mare crust and flooded the added areas with fresh lava—novabase." Later there were ash explosions from vents all over the moon, either associated with large craters, of which they were the final activity, or with small craters independent of larger predecessors.

"Shrinkage and Appression" is the title of chapter xxiii of Part II. In addition to general moon shrinkage, which Spurr considers responsible for much of the lunar relief, "there has been established the existence of an east-west contraction also, evidenced by appression, along north-south axes, of the slumped material around deflated and subsided craters. This condition appears a general and moon-wide one" (p. 263). The author also points out and emphasizes the fact that the low wrinkle (compression) ridges, visible on the surfaces of the maria, are predominantly oriented in a north-south direction although, in many places, their trends curve correspondingly with mare "shorelines" (see Fig. 65, p. 270). Meridional alignment of these several features receives much consideration. But the lack of any great chain of mountain folds, so familiar on the earth, is barely mentioned (Part I, p. 108). Perhaps, however, the author, studying inductively the observed lunar features, did not feel concerned with possible features not seen, although rather peculiarly absent. Doubtless, also, we should expect to see less lunar than terrestrial folding because, with no great difference inherent in the rock material, the smaller body would have (on the scale-model principle stressed by M. K. Hubbert) much greater strength, relative to deforming forces operating within it, than the much larger earth. But, even so, the apparent lack of strong folding on the moon seems so strange that the possible controlling factors should receive critical investigation.

Geology Applied to Selenology is an important contribution to the ultimate solution of many lunar problems and perhaps also of certain geologic problems which should be illuminated by the light reflected from the moon. Spurr has indeed made a very painstaking study.

R. T. C.

Phosphates and Superphosphates. By A. N. GRAY. 2d ed. New York: Interscience Publishers, Inc., 1943. Pp. 416; tables 155. $7.00.

This pocket-size, leather-covered volume written in England and published under the

auspices of the International Superphosphate Manufacturers Association is a carefully compiled volume of statistical, historical, and general information on the rock phosphate and superphosphate industries. It contains little geological infomation but much information of value to the geologist seeking a fuller understanding of the economics of the phosphate industry. The first edition was published in 1930. In this second edition the statistical tables which make up over a third of the volume are brought up to 1939, the last pre-war year. The historical and general part has been greatly amplified.

Chapter i on phosphates and their uses traces the emergence of the present rock-phosphate industry as a result of the inadequacy of the supplies of bones for agricultural uses. The large rock-phosphate deposits of Estramadura, Spain, were known as early as 1808 but were not used for fertilizer. The use of rock phosphates for fertilizer dates from 1842, when a patent for their treatment by sulphuric acid was issued to the English agriculturalist, John Bennet Lawes. He used phosphatic nodules from Pliocene beds of England.

Since these early beginnings the bulk of all rock phosphate has been treated with sulphuric acid to produce superphosphates. It was not until World War I, when a shortage of acid existed, that any noteworthy amount of raw, untreated phosphate was used agriculturally, and the amount still so used is less than a million tons out of the total production of nearly 13 million (1939). The calcining of rock phosphate for the manufacture of phosphoric acid was also a development of World War I.

Chapter ii on the production of phosphates gives a brief world chronology of rock-phosphate mining. Notable among the later items in this chronology was the development, beginning in 1930, of the great apatite-bearing deposits of the Kola Peninsula in northern Russia. This apatite is concentrated by flotation and not only takes care of Russian needs but has provided some surplus for exportation to other European countries. The deposits yield six hundred thousand tons of concentrates annually, and the reserves are large. For the world as a whole the early development of the rock-phosphate industry was slow, and not until it was forty years old in 1887 did the production reach a million tons. The most rapid increase has been since 1919.

Chapter iii deals with composition and grades, and numerous representative analyses are quoted. While the most important item is, of course, the calcium-phosphate content, certain minor components, such as carbonates, iron, aluminum, and fluorine, have each a critical importance, which is fully discussed. It is noteworthy that considerable fluorine is recovered incidental to the manufacture of superphosphates.

Chapter iv is devoted to world distribution and reserves. Estimates of known reserves, based mainly on figures of the American Phosphate Rock Institute, for the world's four principal producing areas are:

	In Billions of Tons
North Africa (with Egypt)	3.7
United States of America	7.4
Islands in the Pacific and Indian oceans	0.2
Russia in Europe	5.5
Total	16.8

Minor areas outside these four raise the world's total to 17.4 billion tons. Estimates of "probable" reserves made in 1926 for the International Geologic Congress are immensely greater, totaling 467 billion tons. Of the Russian reserves, those of the Kola Peninsula apatite deposits are the largest, totaling over 2 billion tons.

Chapter v deals with consumption. World consumption in 1939 was approximately as follows:

	Per Cent
Europe, including Russia	56.5
North America	25.0
Australia and New Zealand	8.0
Asia and Africa	10.5
	100.0

It is noteworthy that many parts of the world use almost no rock phosphates; this is true of South America, Africa, and Asia except for Japan. The future will see increased demands in those areas.

There follows a chapter on trade in phosphates, and the next five chapters are devoted to superphosphates—their origins, history, production, consumption, and trade.

A chapter is devoted to double superphosphate, calcined phosphates, and phosphate of ammonia. A chapter deals with basic slag and another with phosphoric acid.

The last third of the book is devoted to

statistical tables, showing production, imports, exports, and consumption of phosphate rock and of superphosphates for all countries.

E. S. B.

The Rocky Mountains. By WALLACE W. ATWOOD. New York: Vanguard Press, 1945. Pp. 324; halftones 32; maps 3, with 8 cross-section drawings by ERWIN RAISZ. $3.75.

This is the third volume in the "American Mountain Series," edited by Roderick Peattie, its predecessors having treated *The Great Smokies and the Blue Ridge* for the southern Appalachians, and the Green, White, and Adirondack mountains as *The Friendly Mountains*. To the reviewer this new book brought back vivid recollections of the companionable Dr. Atwood, amid pack trains and around campfires, enjoying to the full an invigorating outdoor life and the scenic beauties of the Rocky Mountains, while engaged in unraveling their eventful geologic story. Many former members of his western field parties will enjoy similar memories, awakened by the experiences and studies which Atwood now brings to his readers, who may possibly wonder whether the Rockies have given the author keener satisfaction in discovering and interpreting geologic facts or as an appreciative camper, enthusiastic horseman, and mountain-lover. In the intertwining of the two elements lies the charm of the book.

The reader soon learns how a season of field work is conducted and how mountain structures and scenery tell their tales of past events. Then the mountain drama unfolds, bit by bit, as we move about in different parts of the Rockies, where the party sees many significant things and comes to understand and visualize how the mountains rose, were worn away, rose again, and since have been carved to their present state. Abundant humorous narrative mingles freely with artistic description and simple, effective exposition.

"Bonanza in the Rockies," the longest chapter, is the glamorous story of prospecting and mining, particularly in the pioneer days of high lights and deep shadows. The lively accounts of the discovery and rise of the different mining districts are entertaining as well as instructive. Indians, cattle roundups, cowboy songs, ranches, and tourists are the substance of another chapter, while the final one describes briefly the national parks in the Rocky Mountain region. Quite helpful is the folded relief map, by Erwin Raisz, of the mountainous belt and its environs from north of the Athabaska River to south of Albuquerque. Eight cross-section block drawings by Raisz give in generalized form the geologic structure of selected portions of the ranges. A geologic calendar for the Rocky Mountain region and a Bibliography complete the volume.

Some unfortunate errors should be noted. Facing page 100 are two photographic illustrations labeled: (1) "Devils Tower. An ancient laccolith in eastern Wyoming. This rises four hundred feet above the surrounding lands"; and (2) "Ship Rock, Arizona, and the Great Dyke." The Devil's Tower, however, rises fully twice the specified height above its immediate base and three times that height above the land a short distance away. Fortunately, on pages 121–22 the size of the tower is better appreciated, and the volcanic-throat interpretation supplants the laccolithic hypothesis. Ship Rock is in New Mexico, not in Arizona.

The mountain climber, whose numbers have been increasing rapidly in recent years, may feel that he is the forgotten man. The short, relatively simple walk from where the horses are left to the top of Uncompahgre in the San Juans (the one peak climbed) will hardly satisfy the mountaineer who carries rope and ice ax; he would call for a real job in the Tetons or the Canadian Rockies. But for most readers, hoping for pleasurable reading while acquiring substantial knowledge and true appreciation of this fine vacation country, *The Rocky Mountains* will be found well worth while.

R. T. C.

Topographical and Archaeological Studies in the Far East. By J. G. ANDERSSON. (Museum of Far Eastern Antiquities, Bull. 11.) Stockholm, 1939. Pp. 118; figs. 60, pls. 56, maps 9.

This volume presents the results of the author's studies in six widely separated parts of China, beginning with the Western Hills of Peking in 1914–20 and ending with the coast of Tonkin and Hong Kong Colony in 1938. The six areas of research are (1) Western Hills of Peking, (2) Honan, (3) Kansu, (4) western Szechuan, (5) Tonkin, and (6) Lantau Island, Hong Kong.

Following a period of deep vertical erosion

(Fen Ho) in northern China, the valleys were partially filled (Malan stage) with voluminous gravels interbedded in their upper part with sheets of loess. After the gravels came deposition of the main body of loess. Much later a new cycle of erosion (Pan Chiao) set in, trenching the Malan gravels to depths of 30–60 meters in some valleys and in places cutting through the Pleistocene gravels into the bedrock.

In 1937 the author was surprised to find gravel terraces of the Malan type also abundant in the high Tatsienlu region of western Szechuan near the Tibetan border. Arnold Heim had previously (1933) correlated one of these with moraines of the Mosimien stage of glaciation. Andersson thinks it premature to accept this correlation as proved but states that, if Heim's conclusion be fully substantiated, we should have a powerful means of correlating the late Pleistocene geology of China and the history of early man in Asia with the better-known time record of Europe. All the other regions studied by Andersson are far from areas of glaciation, but he believes that climatic changes, together with some possible crustal warping, have been responsible for the sequences noted.

The Tonkin studies deal chiefly with limestone caves and with some open-air sites of early human habitation.

The volume is unusually well illustrated; many beautiful views testify to the photographic skill of the author.

R. T. C.